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15 February 1962

TRANSLATIONS FROM THE SOVIET JOURNAL OF ATOMIC ENERGY

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15728

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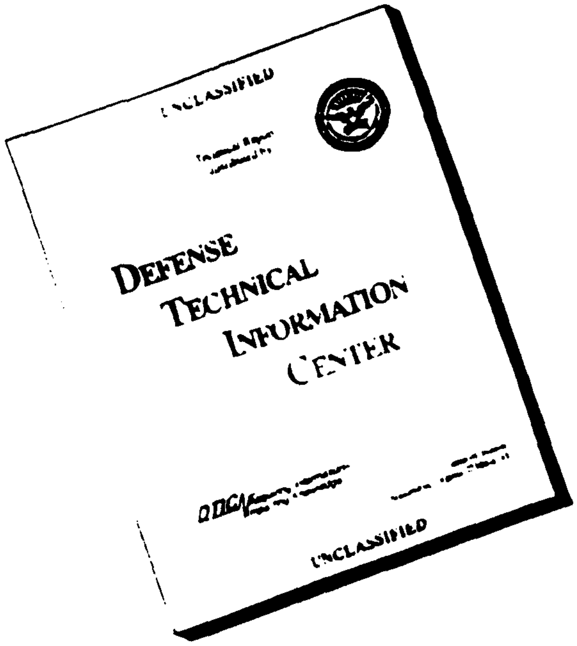

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TRANSLATIONS FROM THE SOVIET JOURNAL OF ATOMIC ENERGY

[Following is the translation of several articles published in Atomnaya Energiya (Atomic Energy), Vol II, No 4, October 1961. Additional bibliographic information accompanies each article.]

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ATOMIC SCIENCE AND TECHNOLOGY AND COMMUNIST CONSTRUCTION

/Following is the translation of an article by V. S. Yemel'yanov, Chairman of the State Committee on the Uses of Atomic Energy of the USSR Council of Ministers, in Atomnaya Energiya (Atomic Energy), volume 11, # 4, October 1961, pps. 301-312./

The Draft for the new Soviet Communist Party Program contains the following statement: "... the development of new technology will be applied toward the radical improvement and facilitation of working conditions for the Soviet people, shortening of the working day and improvement in living standards, the liquidation of hard physical labor, and finally the elimination of all unskilled labor".

Advances in the physical sciences and nuclear physics in particular open up great new possibilities for achieving the goal of constructing a new communist society.

Atomic energy, in its role of a new and powerful source of highly concentrated energy, can effect a considerable increase in the per capita power output of the Soviet Union, making it possible for the Soviet economy to solve problems whose solution could not even be approached on the basis of usual power production facilities. Radioactive isotopes as radiation sources create wonderful possibilities for the automation of industrial processes and the replacement of men by machines. Isotopes are likewise gaining wider use in medicine, scientific research, and the most varied sectors of the national economy.

Scientific researches and studies in the field of nuclear physics are presently at different stages and levels of development, so that the scale of efforts to apply their results is likewise variable. The most advanced research fields at this time have to do with the harnessing of the fision energy of heavy nuclei (uranium and plutonium). These processes have already

found practical application in the form of electrical powerstations and other power-producing facilities.

The world's first industrial atomic electrical powerstation with a 5000-kilowatt capacity was put into operation in the Soviet Union over 7 years ago and has been functioning successfully and without interuption since that time. Work is now being completed on the construction of a first line of major atomic electrical powerstations near Voronezh and in Beloyarsk.

The uranium-graphite reactor at the Beloyarsk Atomic Electrical Power Station imini I. V. Kurchatov has an electrical power-producing capacity of 100,000 kilowatts and represents an original design developed by Soviet specialists. Using slightly enriched uranium, this reactor produces superheated steam at a pressure of 100 atmospheres. Thus, for the standpoint of its operating perameters, the Beloyarsk reactor will be the finest in the world.

The Novo-Voronezhskaya Atomic Electrical Power Station is based on water-water reactors each generating 210,000 kilowatts of electric power.

With Soviet assistance, both Czechoslovakia and the German Democratic Republic are building experimental electrical power stations. The 150,000 kilowatt atomic electrical power station in Czechoslovakia is to be furnished with a reactor which uses heavy water as the moderator and carbon dioxide as the heat transfer agent. In the Germany Democratic Republic, the power capability of the first line in an electrical power station based on a water-water reactor totals 70,000 kilowatts.

Research carried on by Soviet scientists and engineers in the field of atomic energy is accompanied by the construction of numerous research and experimental nuclear reactors and assemblies of various types and power capabilities. This includes reactors which employ graphite, ordinary and heavy water, and organic fluids as moderators as well as heavy and ordinary water, organic fluids, and molten metals as heat transfer agents. Designs have been worked out for reactors based on neutrons of various energies, varying netron flow densities, functioning on a continuous and pulsed basis.

As is known, the Soviet Union has at its disposal enormous reserves of organic fuels and hydro-electric power resources which can satisfy the country's needs for a sufficiently long period; on the other hand, the USSR likewise has regions which are far removed from any of the conventional power supply sources. The new CPSU (Communist Party of the Soviet Union) Draft Program which

will be considered at the 22nd Congress contains the following statement: "As the cost of producing atomic energy decreases, there will be expanded construction of atomic electrical power stations, especially in regions which lack other sources of energy..."

The planning, construction, and operation of all the aforementioned and other atomic electrical power stations with different types of reactors will result in the accumulation of a large body of practical experience which will make it possible to carry out analyses and technical-economic evaluations leading to the discovery of still better methods of building reactors and atomic electrical power plants.

In particular, our scientists have built one of today's most promising reactors--the experimental reactor based on fast neutrons which ~~reached~~ criticality in June 1958 and has been successfully functioning for over 3 years now. Reactors of this type make it possible to obtain up to 1.5 kilograms of plutonium for U-233 in place of each "burnt up" kilogram of U-235 or plutonium at the expense of improved neutron balance. This opens up perspectives for the considerably fuller use of nuclear fuel resources.

If at the present time, the standard reactors based on thermal neutrons use up only 0.4-0.5 of all uranium extracted, i.e., not more than 5 kilograms of each 100 kilograms, while thorium can be used as a nuclear fuel only through the considerable expenditure of U-235, reactors based on fast neutrons make it possible to use both U-238 and thorium fully. With the aid of such nuclear reactors, it is possible to design electrical power stations of greater power producing capability with a relatively low annual uranium expenditure.

Calculations point to the possibility of constructing atomic electrical power stations with a total capability of, let us say, 100 million kilowatts, which, through the use of reactors based on fast neutrons will expend less than 1000 tons of natural uranium each year. As is known, conventional electrical power stations based on coal require 200-300 million tons of coal per year to produce an equal amount of power.

At the present time, considering reactors with expanded reproduction of the fissionable material and the full use of uranium and thorium, one may consider the problem of using chain fission reactions of the heavy elements (uranium and thorium) to obtain large quantities of electrical energy as having fundamentally been solved. Atomic electrical power stations with reactors capable of

assuring expanded reproduction of the nuclear fuel have not as yet been actually tested, while the problem of obtaining large quantities of electrical energy at the expense of uranium and plutonium fission reactions has not as yet received full study from the technical and economic viewpoint. Studies in this area are presently being conducted in the Soviet Union, as well as in the US., Britain, and France.

The quantities of fissionable materials required to stoke fast-neutron reactors are still quite great; it is necessary to accelerate the nuclear fuel reproduction cycle as well as to solve certain other technological problems.

The further automation and improvement of processes involved in the extraction and purification of plutonium or U-233 from fission fragments and the automation of heat-generating element production, along with the development of economically feasible reactor designs, represents one of the most important tasks along the path toward the wide use of nuclear fuel for the creation of an extensive atomic power base.

Reactors with a high degree of nuclear fuel breeding in combination with other reactor types must be carefully studied with reference to the problems of electrifying the entire country and making wide use of atomic energy in industry.

Along with the development of nuclear reactor designs for electrical power stations and research purposes, Soviet specialists have created reactors to be used in naval vessel power installations. The Soviet Union, having at its disposal a number of first-class atomic submarines presently engaged in the defence of waters around our Motherland, is devoting a great deal of attention to the peaceful uses of atomic energy in its merchant marine fleet. In 1960, the flagship of the Soviet icebreaker fleet, the atomic icebreaker "Lenin", made its maiden run over the Northern Sea Route.

The table below contains some data on the Soviet icebreaker as compared with the first American atomic-powered merchant vessel, the "Savannah". /See Table 1 at end of report/.

For the first time in the history of the Arctic, a fleet of Soviet vessels headed by the atomic icebreaker "Lenin" sailed from the Kara Sea toward the Laptev Sea in the East. The icebreaker "Lenin" led 92 vessels through the hummocky icefields of the Northern Sea Route, where the thickness of the ice layer sometimes reached 2.5 meters.

Thus, we have already had our first experience with the use of atomic energy to power an icebreaker; this experiment confirmed the excellent results obtainable with Soviet-designed reactors for ship power installation.

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One of the most important problems involved in the wide development and application of atomic energy is that of radioactive wastes. The production of plutonium and reprocessing of heat-generating elements at atomic electrical power stations and power facilities, involves the formation of large quantities of radioactive waste which undergo only partial disintegration over a short period of time and present a danger for humans for many decades to come. Some of the fragment radio-isotopes are finding practical application in industry, medicine, and other areas. The scale on which they are employed is as yet insignificant, however.

In our country, radioactive wastes given off in the purification of heat-generating elements coming out of the reactors, are stored in special facilities designed for the purpose. In the US and Britain, radioactive plutonium wastes are dumped in the seas and oceans, which not only creates a danger of radioactive contamination for the animal and plant life in the seas, but also is a threat to humans. Radioactive substances accumulate in plant and animal organisms, some of which are consumed by man.

Biological, medical and genetic studies of this problem have provided sufficient evidence of the pernicious effects of radioactive contamination on humanbeings and require the development of special measures to combat the penetration of radioactivity into the human organism.

Soviet scientists are devoting a great deal of attention to the study of radiological problems connected with all of the possible forms of radioactive contamination. Research is being carried on to discover ways of burying radioactive wastes in such a manner that the radioactive material will never escape control so as to contaminate surrounding areas and inflict harm on humanbeings.

In order for atomic power production to play a significant role in the general power production system in the Soviet Union, it will be necessary to effect a considerable decrease in the cost of electrical power produced at atomic electric power stations.

One of the most important problems in the field of nuclear power production is the working out of methods

for the direct transformation of the energy of nuclear processes into electricity.

In the Soviet Union, research on the direct transformation of heat into electrical energy has been under way for a long time. Academician A. F. Ioffe developed not only the theory of thermal electric transformers but also directed the construction of the first thermal batteries. New semi-conductors developed by Soviet scientists exhibit even higher technical qualities and retain their properties for a long time.

In a nuclear reactor, energy can be produced at extremely high temperatures, and this creates favorable prospects for obtaining high efficiencies in the transformation of fission energy into electricty. The direct transformation of nuclear energy into electrical energy will result in the considerable simplification of electrical power producing schemes, thereby having an enormous effect on various branches of technology. For this reason, the new Party Draft Program explicitly expresses the need for further research on methods of "directly transforming thermal, nuclear, solar, and chemical energy into electricity..."

It is obvious that with the great prospects now facing atomic energy, much attention must be devoted to the physics of nuclear reactors. Soviet scientists are conducting various studies in this area, extending them systematically as the fundamental basis of industrial development. As an example, we might mention one of the trends in this work.

In 1960, the unified Nuclear Research Institute at Dubna put into operation a new nuclear reactor designed for research purposes in the area of neutron physics; the design for this reactor bears the stamp of great originality. This is the world's only reactor based on the use of plutonium rods and a disc bearing U-235, revolving at a rate of 5000 revolutions per minute. At maximum pulse height, this reactor attains a power of 3000 kilowatts. It is capable of producing a globular neutron burst of 10^{17} neutrons per second at a periodic rate of 8.3 times a second at the pulse maximum.

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Over the past few years, in addition to the application of atomic energy in power production, there have been important developments in the use of radioactive isotopes and nuclear radiation.

At the present time, radioactive and stable isotopes and nuclear radiations in our country are being employed by over 2500 research, medical and industrial organizations. Practically all branches of the national economy today, although to varying degrees, are making use of radioactive isotopes. Soviet industry is now producing over 300 radioactive and stable isotopes in the form of radioactive sources and tracer compounds.

Isotope products are being widely distributed both inside the country and exported to the People's Democracies, Japan, the UAR, Iraq, Mexico and other countries.

But the practical application of isotope techniques is actually only beginning. It will undergo continual expansion: full use must be made of this newly-conquered force of nature. In this connection it should be noted that at the present time, only about 1-10th of the radioactive and stable isotopes known to science are in actual use.

The utilization of radioactive isotopes as tracer atoms in scientific research and for many other purposes has become an integral part of actual scientific and industrial practise. Important advances have likewise been made in techniques based on the penetrating power of ionizing radiation the injury it inflicts, energy generation, the activation of other materials, etc.

Various devices based on the use of radioactive isotopes to a great degree satisfy the needs of modern industry which is today characterized by a great acceleration of various processes, the utilization of high temperatures and pressures, and automatic regulation. Thus, for example, in both ferrous and non-ferrous metallurgy, radioactive isotopes and ionizing radiations make it possible to maintain continuous control over the automatic mixing of metals and crystalization processes, as well as to create techniques for continuously controling rolled plate and ribbon thicknesses, and blast furnace stoking processes; in the machine building industry, isotopic methods are employed in product defectoscopy and surveillance over machine and instrument wear; in the building industry, isotope instruments are used to control the quality of concrete structures during the pouring process and to check the strength of reinforced concrete members.

Radioactive methods have likewise gained wide acceptance in geological survey work and mineral prospecting. According to the Economics Institute of the USSR Academy of Sciences, 2.2 million tons of high-quality petroleum have been discovered by these methods in

abandoned well holes in the Western Ukraine and Azerbaydzhan alone. According to data from the same source, the economic effect of using radioactive methods in prospecting and ore survey work amounted to over 45 million roubles in 1960.

Great possibilities are likewise opened up by the use of ionizing radiation for the realization of various radiochemical processes.

As examples of economically profitable processes, one can already today cite the oxidation of organic compounds, including benzene, and the radiation polymerization of a number of organic compounds, making it possible to obatin materials with considerably improved properties. The radiation synthesis of polyethylene makes it possible to carry out the process at pressures of 250-300 atmospheres and temperatures of 30-80 degrees C without the use of catalysts. The use of insulation made of stable polyethylene in the electrical industry makes it possible to lower copper expenditures through increased current carrying capacity without lowering the durability of the cable.

These and many other applications of radioactive isotopes demonstrate that radioisotope techniques have become an important tool in the development of technology within the national economy.

At the present time, radioactive and stable isotopes in the Soviet Union are employed in the production of over 700 various chemical compounds.

Radioactive isotopes and nuclear radiations are opening up great prospects in medicine, finding wide application in the diagnosis and treatment of a number of disorders. For example, with the aid of radioactive isotopes it is possible to study the functions of certain organs and organ systems without interfering with their functioning. Thus, the J-131 isotope is used in the diagnosis of thyroid disorders. The P-32 isotope enables physicians to determine the amount of blood circulating in the organism. The diagnosis of brain and nervous system tumors is accomplished through the use of radioactive isotopes of radon, xenon, and iodine. External irradiation techniques with devices using Co-60 and Cs-137 for treating skin, esophagus, lung and other cancers have been developed.

There are also new methods of radio-surgical, intercavity and inter-tissue radiation treatments which are employed in conjunction with external radiation. These make use of Co-60, Cs-137, Au-198 isotopes in colloidal solution, granules of Y-90, etc.

The above examples of the use of radioactive isotopes

and radiation in medicine only partially illustrate the enormous possibilities of the peaceful uses of atomic energy on behalf of mankind.

Agriculture can also be benefitted widely through the use of isotopes; in the future, we shall expect the discovery of new possibilities and prospects, particularly in the use of radioactive radiation in the canning of agricultural products.

Modern technology has at its disposal a wide range of radioactive isotopes of varying energies, half-lives, and other properties. This makes it possible for technicians to solve problems about which one could not even dream in the past. For example, the use of radioactive isotopes in automation can be an important means of solving one of the problems posed by the new CPSU program: "...The liquidation of hard physical labor, and then of all unskilled labor in general." Thus, for example, in the ore extraction and enrichment branches of industry, the operations involved in pulverizing, transporting, and enriching coal and ore, in which the performance of monotenous and simple functions requires the presence of men in an atmosphere of ore and coal dust and constant machine noise, the use of devices based on radioactive isotopes will make possible the complete automation of industrial processes and to replace human labor with machines. The first industrial experiments on the use of radioactive devices at the Krivoy Rog Southern Ore Enrichment Combine and at the Shale Desposits in the Estonian SSR have fully confirmed this possibility and opened up yet another method of employing radioisotopes.

The use of isotopes in the coal industry for the automatic stabilization of the coal extracting combine at the "ore-coal" contact boundary makes possible the maintenance of continuous control overthe position of the cutting instrument and the complete exploitation of the rapid-action capabilities of the combine. This is a techniques which in the future can lead to the complete automation of underground operations and the transfer of machine control to the surface.

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As is apparent from the foregoing, atomic energy today is finding practical applications not only in the military field, but in various sectors of the national economy as well. It has left the confines of the laboratory and has entered the wide open spaces of industrial exploitation. After the completion of test runs on existing and future atomic electrical power stations and

reactors, and after work is completed on the evaluation and compilation of the best types of designs, followed by the selection of the best, most reliable, and economical types of equipment, wide prospects will open up for the construction of electrical power stations and power facilities, while radioactive isotopes and radiations will find even wider use in the national economy.

The foundation of our efforts on the uses of atomic energy is the powerful scientific base which is receiving so much attention from our Communist Party. This scientific base, in particular, assures the discovery and development of new scientific and practical perspectives.

The scientific elaboration of various problems in nuclear physics already today is opening up new and even more attractive possibilities for using the energies of nuclear reactions.

The use of atomic energy drawn from the fission of heavy element nuclei is not the only possible means of using the energy hidden in the atomic nucleus. At this point, one should first of all mention the problem of controlled thermonuclear processes whose solution is one ofthe most important task posed by the Communist Party of the Soviet Union.

Academician I. V. Kurchatov already in 1956 spoke before the 20th Congress of the CPSU about the great role to be played in science and the economy by the solution to the problem of controlled thermonuclear reaction. He said that today in the hydrogen bomb we are already able to create conditions for the fusion of hydrogen nuclei, i.e., to achieve thermonuclear synthesis, but that it is now necessary to control this reaction in order to avoid an explosion.

Soviet research on controlled thermonuclear synthesis is being carried on on a wide front. A number of major installations of various types have been constructed for this purpose, including the largest experimental facility called the "Ogra" with a vacuum chamber 1.4 meters in diameter and 12 meters long; several other such installations are presently under construction. We are confident that the problem of practically employing controlled thermonuclear processes will be solved.

In working on the problem of thermonuclear synthesis, studies are made of processes which take place a temperatures of millions of degrees, when matter is transformed into plasma--a new and little-known state. Research in this area has given rise to a new field of physics--plasma physics. The development of this field is of considerable importance since the successful completion of work on thermonuclear synthesis will completely satisfy the energy

requirements of the entire world population for all time to come. This work is also important by virtue of the fact that it makes possible the discovery of a number of new and practically important data and results. Thus, work with plasma requires the complete mastery of high vacuum techniques (up to $10^{-10} - 10^{-11}$ millimeters of mercury). Experience in this area is of importance to a number of branches of the national economy. Plasma work likewise involves the creation of strong magnetic fields (50,000-200,000 oersteds).

Recently, Soviet research has resulted in the development of intermetallides which posess the property of superconductivity and make it possible to obtain strong magnetic fields under practically realizable helium temperatures, which, of course, is of great importance to other branches of science and technology.

But nuclear physics has still far to go in realizing all its possibilities. Thus, studies of atomic nuclei have led to the discovery of new particles--the so-called anti-particles. Over 10 such new particles have been discovered in the last few years. Most of them have a half-life of less than 1 100-thousandths of a second, while others are stable or have a long half-life.

Table 2 below contains data on some of the anti-particles.

The collision of a proton with its corresponding anti-particle, the anti-proton, is accompanied by an anihilation process characterized by the release of a large quantity of energy approximately 1000 times greater than that given off in nuclear fission or thermonuclear synthesis. The problem of particle anihilation is of serious scientific importance and its study affords a deeper understanding of the structure of matter.

Still another important tool in the study of nuclear structure is the investigation of the effects on atomic nuclei of bombardment by other nuclei and particles accelerated to high energies with the aid of powerful accelerators. This method still remains the most universal one, and will continue to develop in the foreseeable future. Several new large accelerators will be put into operation soon; construction work began recently on the world's most powerful rigid focusing accelerator with a nominal proton energy of 50-70 bev (billion electron volts). Table 3 below lists the most important specifications for this accelerator.

New accelerator installations will result in a still further strengthening of the material base of Soviet studies of nuclear structure.

Likewise of considerable scientific interest is the

Table 1

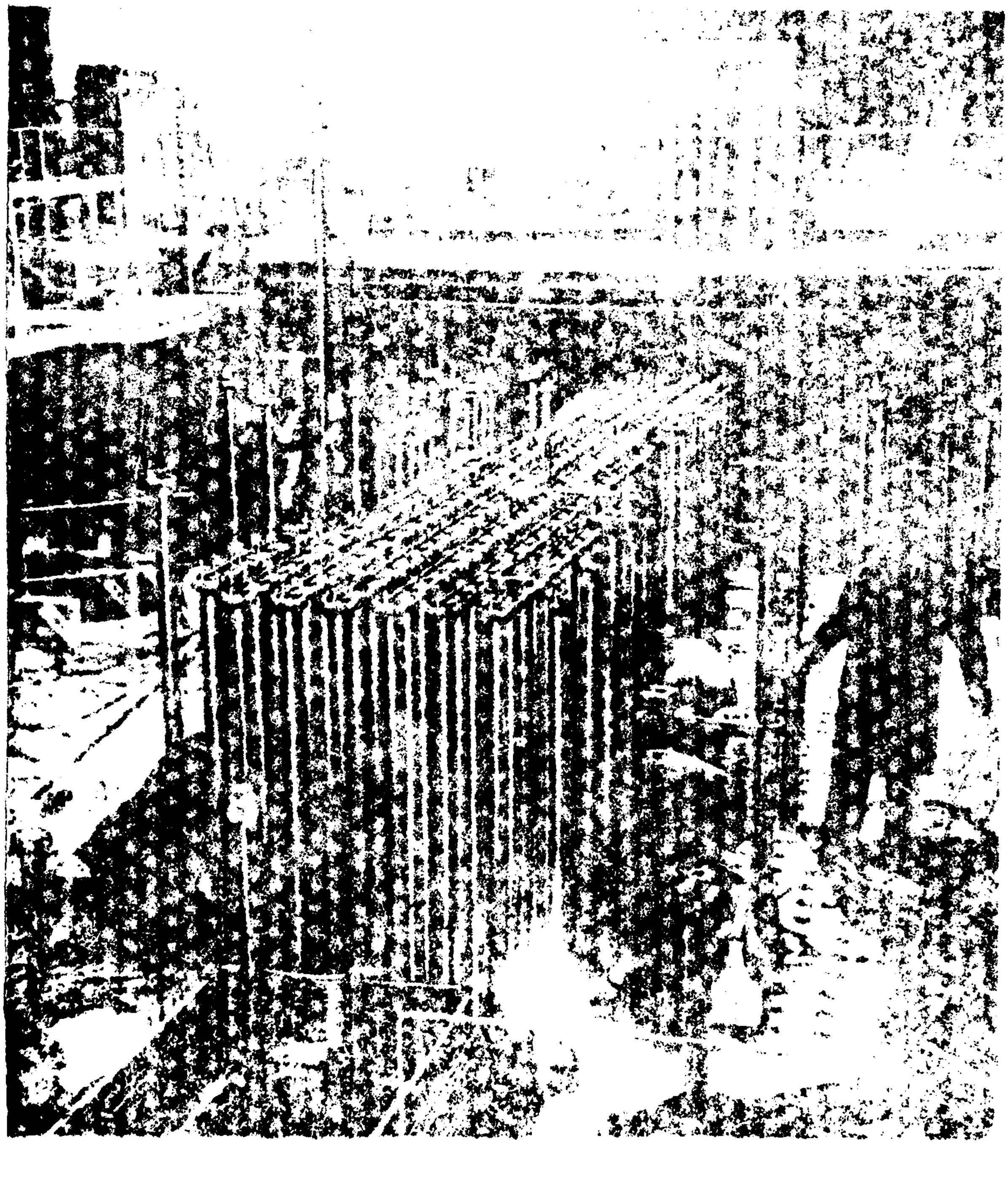
	Icebreaker "Lenin"	The "Savannah"
Completion	1959	1961 (planned)
Displacement, in thousands of tons	16	21.8
Engine power, in thousands of HP	44	20

Table 2

	Mass	Mean Life	Year Discovered
Antiproton	938	Stable	1955
Antineutron	940	"	1956
Positron	0.511	$1.013 \cdot 10^3$ seconds	1932

Table 3

Nominal proton energy, bev....................	50-70
Mean orbital radius, meters....................	236
Maximum field, oersteds........................	10000-12000
Injection energy, mev..........................	100
Number of magnets..............................	120
Total magnet weight, tons......................	>20000



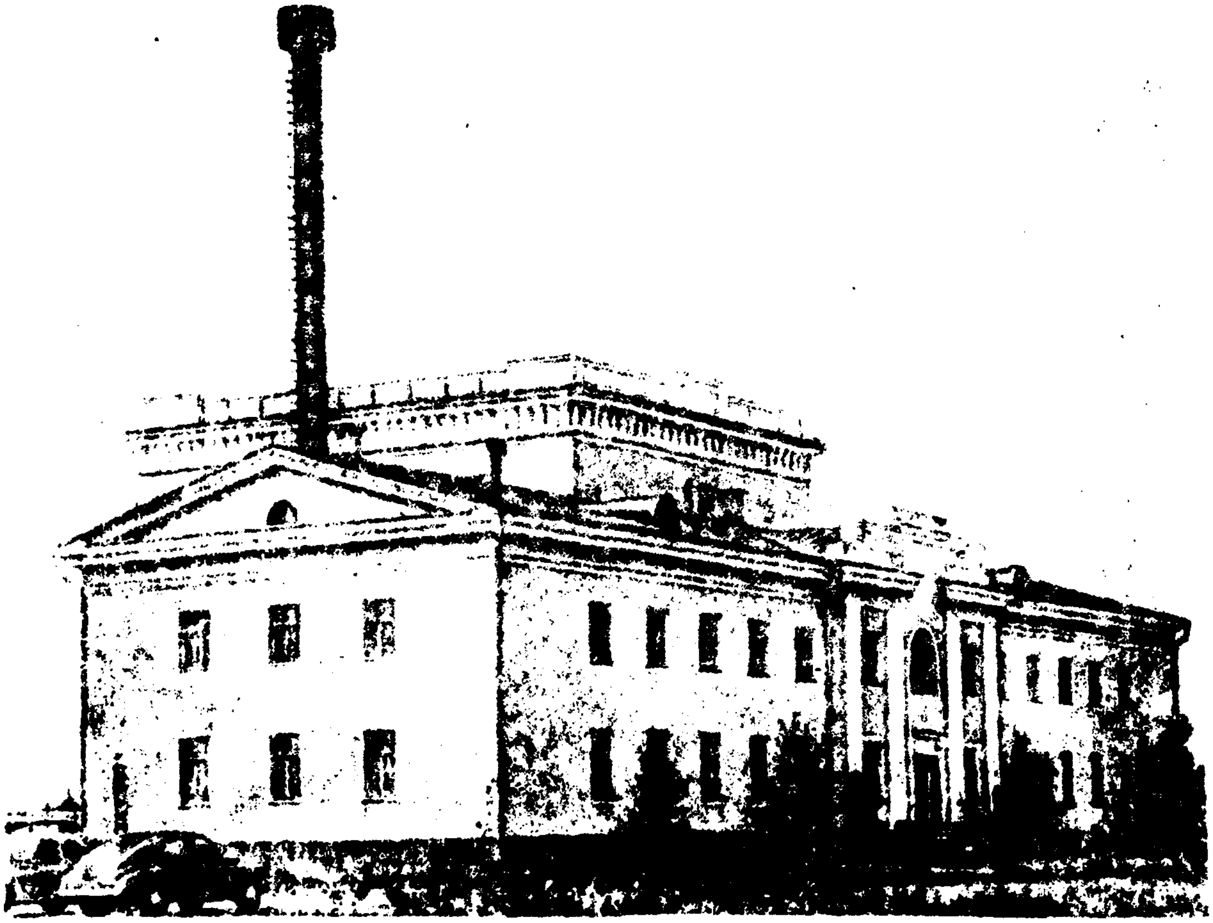
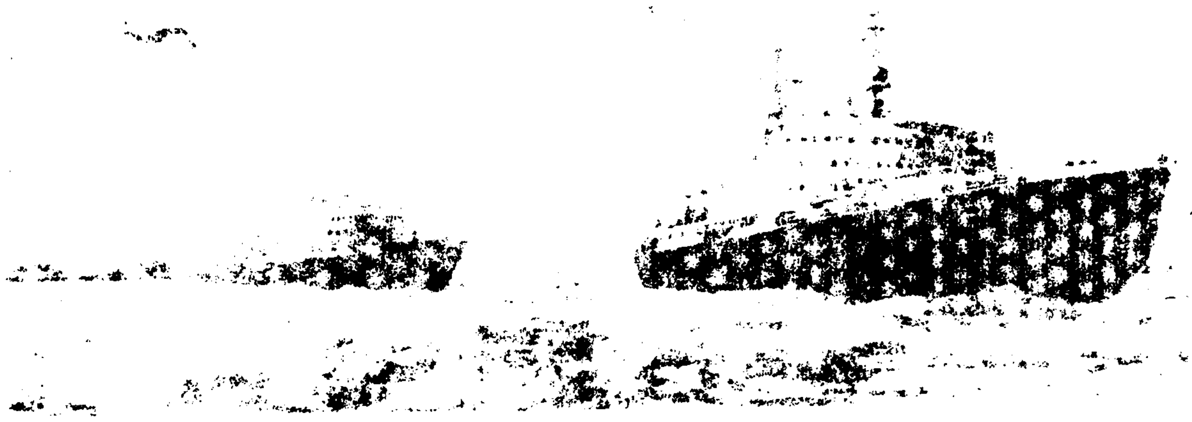


Figure 2. Building which houses fast-neutron test reactor constructed in 1958.



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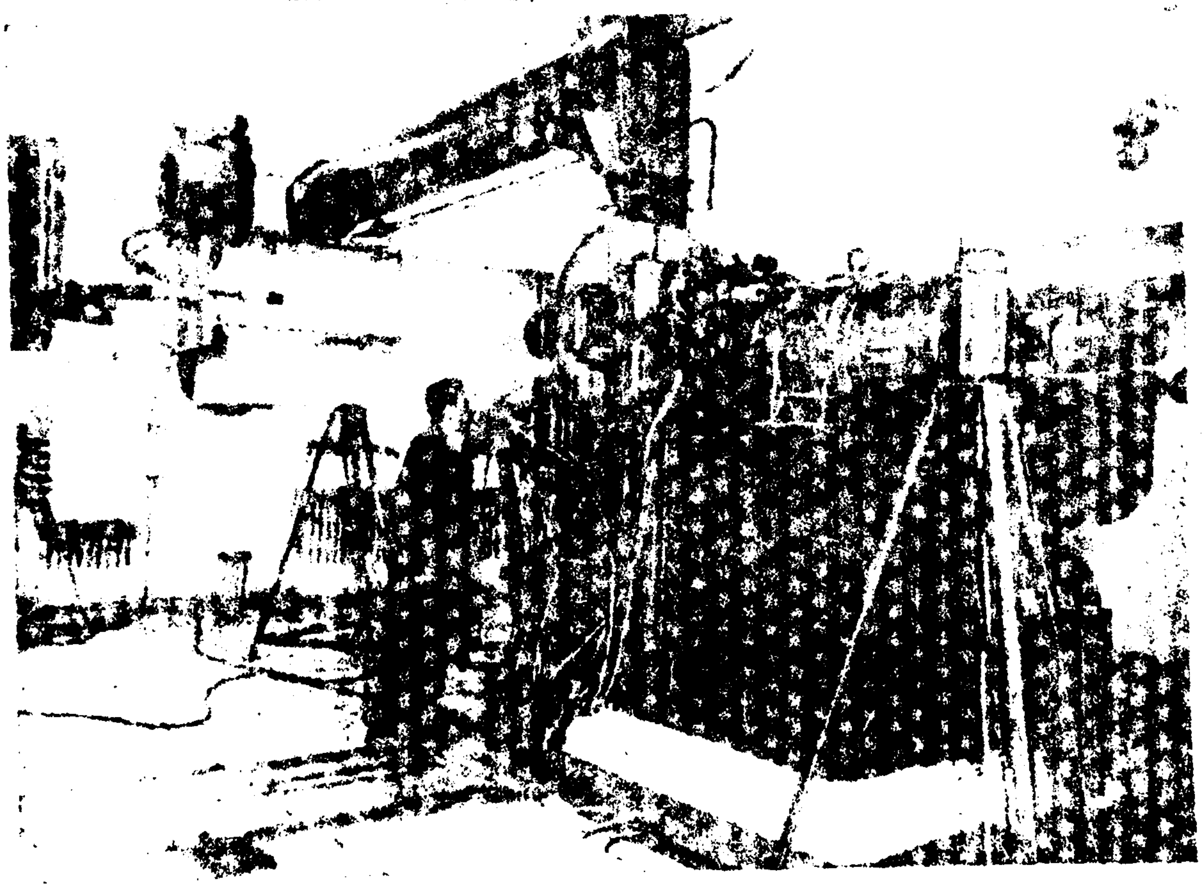

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Figure 5. Exhibit of protective clothing worn in controlling radioactive contamination (pavilion on "Peaceful Uses of Atomic Energy", All-Union Ten-Day Festival of the National Economy, 1961).

Figure 6. Showroom of the "[illegible]" ("Technics") Store in Moscow.

Figure 7. Overall view of the cyclotron for the acceleration of multiply-charged ions of the Joint Nuclear Research Institute at Dubna.

THE INTERACTION OF CHARGED PARTICLE BEAMS WITH PLASMAS

/Following is the translation of an article by Ya. B. Faynberg (assisted in compiling the survey by V. I. Kurilko, I. F. Kharchenko, and V. D. Shapiro) in Atomnaya Energiya (Atomic Energy), volume 11, # 4, October 1961, pps. 313-335./

The interaction of charged particle beams with plasmas plays a significant role in various types of gas discharges present in equipment used in CTR (controlled thermo-nuclear reaction) research. This interaction is a determining factor in a number of new methods for accelerating charged particles, intensifying and generating microwaves with the aid of plasmas.

Despite the apparent diversity and variation in the forms of such interaction, the elementary processes which lie at its basis can be reduced to the Cerenkov effect, anomalous and normal Doppler effects, and the effects of plasma polarization as charged particles move through it. The parametric Cerenkov effect can also play a significant role in the movement of charged particles and oscillators through a limited or spatially-periodic plasma.

Since plasma density n_0 is in most cases relatively low ($n_0 \simeq 10^{12} \div 10^{14}$), the energy lost by a single particle per unit length dE/dx as a result of these effects is small and is on the order of $10^{-3} - 10^{-5}$ electron volts/centimeter. In most cases, however, it is a beam of charged particles which interacts with the plasma. When this occurs, the effectiveness of the interaction increases considerably (reference 1) since the resulting self-modulation of the beam finally leads to a coherent interaction of the beam particles with the plasma (reference 2).

Energies lost by particles in the beam due to excitation can be considerable, reaching $10^3 \div 10^4$ electron volts/centimeter per particle when the number of particles in a particular pulse is $N \simeq 10^7 \div 10^8$. The considerable

effectiveness of beam and charged particle clusters with plasma allows one to expect that it plays a considerable role in a number of processes which take place in gas discharges. Apparently, this interaction is responsible for a number of oscillatory instabilities in plasma, the establishment of Maxwell distributions in the plasma in the absence of collisions, and the alteration of transfer (diffusion and conduction) processes in the plasma.

The increased energy of interaction in the movement of beams or clusters of charged particles through plasma in comparison with the interaction energy of a single particle can be utilized in the development of methods for injecting plasmas into magnetic traps and heating it, as well as for measuring plasma perameters, its distribution functions and studying the processes taking place within it.

In studying the possibilities of realizing CTR, it is most important to investigate conditions accompanying the appearance and termination of oscillatory instabilities arising as a result of charged particle-plasma interactions.

The motion of a beam through a plasma is unstable in those cases where the initial turbulences (fluctuations) existing either within the beam or plasma tend to increase. In order for instabilities to arise, there must be a set of conditions present under which one of the aforementioned elementary processes will take place (the Cerenkov effect, or the anomalous or normal Doppler effects). Since absorption accompanies radiation processes, it is necessary that the number of particles in the beam releasing energy into the electromagnetic field exceed the number of particles absorbing field energy /see Note/. Finally, another necessary condition for the appearance of instabilities is the grouping of particles primarily in that phase region in which the particles release energy into the electromagnetic field. As radiation conditions for one particle are fulfilled, the grouping of other particles takes place automatically in a number of cases. Electromagnetic fields arising as a result of particle emission lead to a grouping process, i.e., to the automodulation of the beam, while the increased degree of beam modulation gives rise to increased radiation intensity due to conditions conducive to coherent emission which appear in the course of particle grouping. /Note: this requirement imposes definite conditions on the unperturbed distribution function for beam and plasma particles with respect to their velocity (see below)/.

From the standpoint of quantum theory (reference 3), the appearance of instabilities indicates that there is a

greater number of induced emission events than absorption events due to the predominant occupation of the "upper" energy levels (by the beam particles). For example, for a free-particle beam, the "upper" levels correspond to particles of greater velocity. For this reason instability occurs if the derivative distribution function for the beam particles is positive for velocities at which the particles interact intensively with the plasma. This result likewise follows from classical considerations.

1) A theoretical investigation of the problem involved in the excitation of longitudinal oscillations by a charged particle beam carried out by A. I. Akhiyezer and the author, as well as by Bohm and Gross (reference 1) confirmed the existence of beam instabilities and showed that their effect was particularly great if the orderly velocity V_0 of the beam exceeds the thermal velocity of the plasma electron V_{T_e} , i.e., if $V_0 > V_{T_e}$. The elementary process at the basis of this interaction is the Cerenkov effect (reference 4) for the case of longitudinal plasma waves. When $n_1 \ll n_0$ the spectrum of excited high-frequency oscillations is determined by the condition for Cerenkov radiation and lies in the frequency range $\omega \simeq \simeq \omega_0$. The rate of instability increase $\delta = \operatorname{Im} \omega$ in this case is rather significant

$$\delta \simeq \omega_0 \left(\frac{n_1}{n_0}\right)^{1/3}$$

Analogous phenomena take place during the interaction of two or several beams (reference 5). Thus, for example, in the case of two electron beams with a Maxwell distribution with respect to the velocity of their ordered motion (reference 6), there likewise arise instabilities provided we have the condition $|V_{01} - V_{02}| > V_{T_{e1}} + V_{T_{e2}}$ where V_0 and V_{T_e} are, respectively, the orderly-motion velocity of the beam and the thermal velocity of the electrons. The rate of increase of these instabilities is relatively large. With definite ratios between beam perameters, we have in this case a longitudinal Doppler effect in which the excitation frequencies are determined by the condition

$$\omega \simeq \frac{\omega_{02}}{1 - \dfrac{V_{02}}{V_{01} - \sqrt{3}\, V_{T_e}}}$$

Further investigations of the problems of plasma excitation carried out by G. V. Gordeyev (reference 7) have shown that the excitation of low-frequency and ionic oscillations (in the absence of a magnetic field) takes place provided that $V_{T_e} \mu^{1/2} < V_0 < V_{T_e}$ i.e., at consider-

ably lower orderly-motion velocities, and, consequently, significantly smaller currents.

Within the last few years, many studies have been carried out on the interaction of charged particle beams and oscillators with plasmas. These studies have resulted in the discovery of a large number (about 20) of individual cases of instability.

Most of these instabilities can be sub-divided into three broad groups according to the elementary processes on which their mechanism is based:

a) instabilities brought about by the Cerenkov effect in the interaction of electron and ion beams with plasma in a magnetic field.

These instabilities obtain when the orderly velocity V_0 of the beam is equal to the phase velocity V_ϕ of the wave, thus leading to the excitation of low- and high-frequency oscillations. Among the low frequency oscillations we might mention ionic-acoustic oscillations, Alfven waves, and magneto-acoustic waves; among the high-frequency oscillations, we have the longitudinal electron fluctuations in a magnetic field.

The excitation of low-frequency oscillations can likewise be brought about by drift currents in a non-homogeneous plasma (references 8, 9). In this case, the role of orderly motion is played by the drift effect, so that the instability condition is reduced to the requirement that $V_{dr} = V_\phi$ (where V_{dr} is the drift velocity).

b) instabilities occasioned by the anomalous Doppler effect.

The condition under which this effect arises is reduced to the requirement that the velocity of the emitting particle exceed the phase velocity of the wave in the plasma $(V > V_\phi)$. Emission frequencies in this case are defined by the equation $\omega - k_z V_0 = -\omega_{res}$ or

$$\omega = \frac{\omega_{res}}{\frac{V_0}{V_\phi} - 1}$$

(where ω_{res} is the velocity of the emitting particle in the system in which it is at rest; $k_z = \frac{\omega}{V_\phi}$ is the projection of the wave vector on the direction of beam travel). In this case, the emission frequency recalculated for the system in which the beam is at rest coincides with the resonant beam frequencies, in particular with the Langmuir beam frequency ω_0 when we have the longitudinal Doppler effect) or the Larmor frequencies ω_H $(\omega = \omega_0 ; \omega = n\omega_H;$ $n = 1, 2 \ldots)$.

An important peculiarity of the anomalous Doppler effect as investigated by V. L. Ginsburg and I. M. Frank

(reference 3) consists in the fact that in the case considered, emission is accompanied by elevation to a higher energy level. For this reason, emission can take place even for unexcited oscillators, including a charged particle beam moving through a plasma in a magnetic field without an initial transverse energy. The transition of freely-moving particles into oscillators and emission take place at the expense of transverse motion energy.

Among the instabilities occasioned by the anomalous Doppler effect, we might mention those involving the excitation of ionic-cyclotronic waves in the plasma by electron and ion beams. The anomalous Doppler effect likewise leads to the excitation of high-frequency electron oscillations with frequencies of about ω_H; $\sqrt{\omega_0^2+\omega_H^2}$, although here the increment of oscillation intensification is less than in the case of oscillations set up by the Cerenkov effect. In all previous cases, the oscillation frequency in the coordinate system of the beam was close to the Larmor velocity of the beam particles. The excitation of plasma oscillations by a high-density beam can be accompanied by a longitudinal Doppler effect in which the oscillation frequency in the coordinate system where the beam is at rest is close to the Langmuir beam frequency ω_0. The oscillation frequency in this case is equal to $\omega \simeq \omega_0 \mu^{1/3}$.

c) instabilities occasioned by the normal Doppler effect.

If an electron moving through a magnetic field has an initial transverse energy, then the motion of a beam of such electrons through plasma can be accompanied by the appearance of instabilities occasioned by the normal Doppler effect. An important peculiarity of such instabilities is that they arise when the beam velocity $V_0 < V_\phi$ [see Note 1], and in particular, when $V_0 = 0$. Thus, emission always takes place in the case of the normal Doppler effect. For this reason, the only condition for instabilities to arise is a particle arrangement such that a greater number of the particles are concentrated in the phase region where they surrender energy to the electro magnetic field than in the phase region where particles absorb field energy [see Note 2]. The mechanism of such an arrangement is treated in the papers of A. V. Gaponov (reference 10). This mechanism is occasioned by the dependence of particle oscillation frequency on its energy. [Note 1: frequencies emitted in the case of the normal Doppler effect are given by $\omega - k_z V_0 = \omega_{res}$.] [Note 2: as the result of the appearance of regular ion motion across the magnetic field, resonant ("currentless", beamless) heating methods

likewise lead to the development of both low-frequency ($\omega \approx \sqrt{\nu_H}$) and high-frequency electrostatic instabilities/.

In the case of the motion of an oscillator through a spatially non-homogeneous field with a frequency $\omega \simeq \omega_{res}$, the mean oscillator displacement over a time which is large in comparison with the oscillation period differs from 0 and depends on the initial oscillator phase. Because of this fact, there is a special grouping of oscillators in the wave field.

Tables 1-3 /see Note/ contain the basic characteristics of instabilities occasioned by the Cerenkov, and the anomalous and normal Doppler effects. /Note: Tables 1-5 are of a strictly illustrative character. They contain data only for the simplest and most obvious cases. The appropriate relationships describing instabilities in more general cases are found in the references cited. These are the most fundamental studies in the field known to us. They cover both the general cases and those included in the Tables./

2) An examination of the Tables shows that instabilities can arise at relatively low electron velocities ($V_0 \gtrsim V_{Te}\,\mu^{1/2}$ and $V_0 \geqslant V_A$).

A reduction of the electron velocity at which the instability arises leads to a reduction of the limiting current value necessary for the excitation of the instability; moreover, it can be less than the limiting current value necessary for hydrodynamic instabilities to occur. Let us note, however, that the limiting current is determined not only by the critical orderly-motion velocity, but also by the density of the electrons participating in the motion. For this reason, a number of instabilities arising at large orderly-motion velocities can result at lower current values, since such instabilities are excited at relatively low electron densities.

The increments of instability intensification listed in the Tables are extremely large. In the case of high-frequency instabilities, the intensification time is on the order of 10^{-9} seconds; it is less for low-frequency instabilities since the increment of intensification is either less than or on the order of the emission frequency. The time for the appearance of these instabilities is also very short ($\sim 10^{-4} \div 10^{-6}$ seconds), however. If we assume that the initial energy of the oscillations is on the order of thermal fluctuation energies, then the time in which the energy of orderly motion can be converted into oscillatory energy assumes a value on the order of 10^{-4} – 10^{-8} seconds.

The plasma retention time in a number of cases exceeds

the instability rise times. This confirms the fact that not all of the instabilities listed play a significant role. Using the increment values, it is possible to compare the energies lost by individual particles and particles moving in beams and interacting with plasmas. In the latter case, the losses per particle are considerably greater than in the former due to coherent beam interaction with the plasma, whose importance was first pointed out by V. I. Veksler (reference 2).

A number of instabilities are characterized by a discrete frequency spectrum, although continuous-spectrum instabilities do exist. The presence of the latter lead to a significant absorption of orderly-motion energy and complicates the development of methods for the elimination of instabilities.

It follows from the Tables, that the velocity distribution in the beams reduces rise times and consequently weakens and even eliminates instabilities. In a number of cases, a wide distribution of velocities leads to the appearance of new instabilities whose rise increments are not large as a rule, however. The instabilities examined apply to a homogeneous plasma for which $\nabla n = \nabla T = 0$. The presence of inhomogeneities leads to a considerable weakening and cessation of instabilities, but, as is shown in the paper by Rudakov and Sagdeyev (reference 9), leads to the appearance of still other instabilities.

Let us briefly examine the significance of instabilities in the operation of a stellarator.

In devices of the stellarator type, $V_0 < V_{Te}$, so that the most important instabilities here are those which arise at $V_0 \gtrsim V_{Te} \mu^{1/2}$, i.e., ionic sound in a magnetic field. These instabilities are characterized by a frequency spectrum $\omega \lesssim \omega_{0i}$, and the increment of instability rise is on the order of

$$\delta_{max} \simeq \omega_{0i} \frac{V_0 - V_{Te} \mu^{1/2}}{V_{Te}}$$

(reference 12). Since instability occurs when $V_0 > V_{Te} \mu^{1/2}$, the critical value for the current density $I_{cr} = e V_{Te} \mu^{1/2} n_0$ at which instabilities involved in the excitation of ionic sound must appear, is quite small. Thus, for example, in the case of the Model C stellarator, the critical current value is equal to 30-100 amperes/centimeters^2. Low-frequency instabilities are apparently more significant in the case of diffusion processes within the plasma /see Note/. /Note: the important role of ionic low-frequency oscillations within a plasma in a magnetic field for diffusion processes in a stellarator has been pointed

out by Spitzer (references 18, 31). The derivation of the diffusion coefficient given in reference 31 is unconvincing in our view; for the corelative function ceases to hold if we are considering diffusion occasioned by unstable oscillations; if on the other hand, we are considering diffusion in a stabilized regime, then the derivation turns out to be indeterminate, insofar as linear theory does not permit us to determine the amplitude of stabilized oscillations. The effect of beam instabilities on diffusion processes can be calculated by a low non-linearity approximation7.

From the standpoint of orderly-motion energy losses, high-frequency, particularly longitudinal, oscillations occasioned by escaping electrons play a significant role. Instability, as is known, arises when $\partial f/\partial v_z > 0$ (where f is the distribution function; $v_z = \frac{eE}{m}(t-t_0)$, i.e., when the number of particles with velocities $v_z > V_\phi$ exceeds the number of particles with velocities $V_z < V_\phi$. The appearance of a region with $\partial f/\partial v_z > 0$ in the distribution functions can take place as was shown by A. V. Gurevich (reference 32) in a stellarator upon the appearance of a current plateau at which the magnitude of the critical field which determines the appearance of escaping electrons increases with time, thus leading to a reduction of the electron flow through the seepage boundary. The flow of escaping electrons S is connected with the distribution function f at $v_z > \sqrt{E_c/E}\, v_{Te}$ by the relationship

$$\frac{\partial S}{\partial t_0} = -\frac{e^2 E^2}{m^2}\frac{\partial f}{\partial v_z}\,; \quad \left[v_z = \frac{eE}{m}(t - t_0)\right]$$

(here E is the electric field intensity and E_c is its critical value). For this reason, the reduction of the escaping electron flow with time will lead to the appearance of a region where $\partial f/\partial v_z > 0$. The instability will occur if the rise increment $\delta \simeq \pi \, \partial f/\partial v_z \cdot v_z^2 \cdot \frac{\omega_e}{N_e}$ is greater than the pair collision frequency. From this condition, we can determine the instability rise time. It is equal to $10^{-4} \div 10^{-5}$ seconds and coincides with experimental data high-frequency oscillation frequencies in this case are about $\sim 10^{10} - 10^{11}$. This also coincides with experimental data.

3) Usually, in considering instabilities it is assumed that the functions of plasma particle distribution with respect to orderly-motion velocity are of the Maxwell type; this assumption is used in calculating excited oscillation spectra and their rise increments.

In the absence of pair collisions in the plasma, the distribution function can be an arbitrary function of the

velocity. In view of this fact, we have the important problem of finding the necessary and sufficient conditions for the instability of the arbitrary distribution function with respect to the oscillation.

For longitudinal oscillations in the absence of external fields, instability conditions have been found by Penrose (reference 33), Nedlinger (reference 34), A. I. Akhiyezer, G. Ya. Lyubarskiy, and R. V. Polovin (reference 35). In reference 35, these instability criteria are generalized for the case of a plasma in an external electric or magnetic field. In the absence of external fields, the instability conditions have the form

$$f_0'(u_e) = 0; \quad \int \frac{f_0'(u)}{u - u_e}\, du > 0; \quad f_0''(u_e) > 0,$$

where $f_0(u) = \int f(\vec{v})\, d\vec{v}$ (here $f(\vec{v})$ is the distribution function; $\vec{v}_\perp$ is the perpendicular to the wave vector $\vec{k}$, and u is the parallel velocity $\vec{v}_\perp$ to component k.)

The conditions $f_0'(u_e) = 0$; $f_0''(u_e) > 0$ mean that there exists a velocity range $v > u_e$ in which $f_0'(v) > 0$. If $f_0'(v = V_\phi) > 0$ then the number of particles moving faster than the wave and thereby surrendering energy to it exceeds the number of particles moving slower than the wave and absorbing its energy, which in turn leads to an increased oscillatory amplitude with time, i.e., to instability. The condition $\int \frac{f_0'(u)\, du}{u - u_e} > 0$ implies the possibility of propagation within the plasma of waves with phase velocities $v_\phi > u_e$.

The question as to the character of the instability is important both in the theoretical and practical realms /see Note/. The instability is absolute if the initial perturbation increases with time in any fixed point in space. If, on the other hand, the initial disturbance is displaced as it increases in the direction of beam travel so that it decreases with time in every point in space, then the instability is called convective. In the case of convective instability, the disturbance, not having had time to reach high values, can be eliminated from the system. The method for separating absolute and convective instabilities described by L. D. Landau and Ye. M. Lifshits (reference 36) is reduced to a consideration of the asymptotic behavior of the integral $\int \exp[-i\omega(k) \times t]\, dk$ as $t \to \infty$, describing the motion of the wave packet. /Note: the system is unstable relative to small disturbances proportional to $\exp(-i\omega t + ikx)$ if the dispersion equation $D(\omega, k) = 0$ of this system has complex solutions for ω or k. If in a given region where is real, the frequency k is complex, then we may have

either absolute or convective instability.7

If for $t \to \infty$ this integral increases without limit, we are confronted with absolute instability. If on the other hand, the integral tends to a limit for $t \to \infty$, the instability will be convective.

As is shown in the paper by Sturrock (reference 37), the interaction of two countercurrent beams is accompanied by absolute instability; convective instability occurs when two concurrent parallel beams interact. Absolute instability in general is present in those cases where there is feed back.

A study of beam interaction with heated plasma carried out by the author together with V. I. Kurilko and V. D. Shapiro (reference 38), as well as by Sturrock (reference 39) has shown that convective instability is present in this case. The instability of self-focusing electron-ionic beams turns out to be convective.

In a number of cases it is difficult to establish whether the oscillations are increasing or diminishing, since even in those systems which lack a source of energy to assure the presence of increasing waves, the dispersive equation admits of increasing solution. Thus, for example, this happens with the problem involving the penetration of a high-frequency field into a plasma for frequencies $\omega < \omega_0$ or in the case of wave propagation in waveguides for frequencies not exceeding the critical value. In such cases, using the condition for emission, we retain only those solutions which correspond to wave diminution. In the presence of a beam moving through an unbounded system there are no standard conditions for emission, so that in order to distinguish the increasing waves we have to study the behavior of the turbulence in the form of a wave packet. Intensification takes place only in those cases where the turbulence described by the wave packet becomes 0 as $x \to \infty$ in any fixed moment in time t. In the contrary case, the wave which increases as $x \to \infty$ cannot exist in the system.

As was shown by V. I. Kurilko (reference 40), for example, in the movement of a plasma through a plasma waveguide, complex values for k correspond to the barrier effect rather than intensification. If a plasma moves through a medium with a dielectric constant ε in orthogonal electrical and magnetic fields, then for $V_0 > c/\sqrt{\varepsilon}$ and $V_0 < c/\sqrt{\varepsilon}$, complex values for $\varkappa$ correspond to real values for ω. But intensification takes place only for $V_0 > c/\sqrt{\varepsilon}$; the case $V_0 < c/\sqrt{\varepsilon}$ corresponds to the barrier effect (reference 41).

Criteria for separation, intensification, and barring,

as well as a simple method of distinguishing absolute and invective instabilities are given in the paper by Sturrock (reference 37). A confirmation of these criteria and the limits of their applicability are given by R. V. Polovin (reference 41).

4) We have just examined the problems involved in the interaction of unbounded beams with plasmas. For this reason, the resulting equations strictly speaking are applicable not only in thoses cases where the geometric dimensions of the system $L_{\parallel}$ and $L_{\perp}$ are considerably greater than the wave length, i.e., if
$\varkappa_{\perp} L_{\perp} \gg 1$, $\varkappa_{\parallel} L_{\parallel} \gg 1$.

In a number of devices and installations these conditions are not fulfilled, which gives rise to a considerable disparity between theoretical and experimental results. The difference between a bounded and unbouded plasmabecomes most clear in the absence of a magnetic field. In such a case, an unbounded plasma will not serve as a propagation medium for slow transverse waves, since for the entire frequency range $\varepsilon = 1 - \omega_0^2/\omega^2 < 1$. This case, moreover, affords no possibility for effective interaction between free particles and waves in the plasma; in particular, the Cerenkov effect cannot occur /see Note/ /Note: according to Neufeld and Doyle (reference 77) the interaction of a beam and plasm in this case can be accompanied by the excitation of electromagnetic oscillations, since the motion of a separate particle through the plasma alters the dielectric constant of the beam and can reduce the phase velocity of the wave down to a value equal to the particle beam velocity./

If, on the other hand, the plasma is bounded in a radial direction, then despite the fact that the value for in the region occupied by the plasma is as previously less than one and even negative, the plasma can contain slow waves. An analogous state of affairs obtains in the case of a plasma bounded in the direction of wave propagation, in particular with spatially-periodic plasma. And in this case case, despite the fact that dielectric constants are less than one or are even negative, slow waves can propagate through the system; furthermore, such a plasma assumes the properties of an anisotropic medium.

The dispersive properties of a bounded plasma in a magnetic field determined by the anisotropy and hypotropy of the medium are combined with wave guide properties determined by the geometry of the system. This likewise leads to a strong disparity in the dispersive properties of bounded and unbounded plasmas. Since the elementary processes at the basis of plasma-beam interactions are to

a considerable extent determined by the dispersion of the system, i.e., by the dependence of the phase velocity on frequency, it might be expected that conditions for the appearance of instabilities (in particular, the critical velocity and beam current), the frequency spectrum, and rise increments will be altered as we pass from a bounded to an unbounded plasma.

Results of studies on instabilities arising through the interaction of bounded beams with plasma show that if the plasma wave length (V_0/ω_0) becomes comparable with the beam radius a, there will be a considerable increase in the wave length of the wave at which instabilities begin to arise; there will be a concomitant decrease in the value of the increment. Thus, for example, in the case of electron-ionic beams studied by G. I. Budker (reference 42), the ratio of rise increments for a bounded and unbounded plasma equals

$$\frac{\operatorname{Im}\omega(a \ll \lambda)}{\operatorname{Im}\omega(a \ll \lambda)} \simeq \frac{V_0}{\omega_0 a} e^{-\frac{2V_0^2}{\omega_0^2 a^2}} ; \quad \frac{\omega_0 a}{V_0} \ll 1.$$

In the excitation of longitudinal plasma oscillations by a beam examined by M. F. Gorbatenko (reference 17) and Sturrock (reference 39), as well as in reference 43, the diminution of the increment can reach values on the order of 5-10. For this reason, the oscillation amplitude decreases quite sharply. It is possible to select perameters in such a way that the limiting wave length will exceed the length of the system. In this case, the particular instabilities involved will not occur. These peculiarities of bounded beam interaction with plasmas are of importance in finding methods for eliminating instabilities.

5) Despite the successes achieved in the theory of charged particle-plasma interaction, the identification of new instabilities accompanying this interaction, as well as the experimental confirmation of basic theoretical conclusions, the theoretical studies so far completed are as yet insufficient for a comprehensive evaluation of the role of instabilities in processes taking place in various types of discharges. This is connected with the fact that most of the completed studies make it possible only to determine the spectrum of oscillations are their rise increments. One of the most important characteristics of instabilities, namely the oscillatory amplitude, is usually neglected. Its determination requires a knowledge of the energy spectrum of the initial fluctuations, the reverse effect of oscillations on the plasma distribution function

and beam particle travel, and an investigation of the transition from linear to nonlinear oscillations along with a determination of the amplitude of established oscillations.

It should be noted that in the case of interaction under consideration, nonlinear effects occur at relatively low electrical field amplitudes. The nonlinearity criterion for plasma wave motions under non-resonant conditions has the form

$$\frac{eE_0\lambda}{mc^2\beta_\phi(1-V_0/V_\phi)^2} \ll 1.$$

for this reason, nonlinear effects are of considerable importance in the region of long wave lengths and low phase velocities. Since in most cases the conditions for excitation may be reduced to the requirement that $V_0 \gtrsim V_\phi$ the role of nonlinear effects in the presence of beams is even greater. It might seem that in the case of ionic oscillations, nonlinear processes occur only at very large field intensities. Actually, even at relatively low intensities, nonlinear effects do take place due to the fact that the ions interact most strongly with slow waves and that long wave lengths λ correspond to slow waves for low-frequency ionic oscillations. Thus, for example, for $\beta_\phi \simeq 10^{-4}$, $\lambda \simeq 10^3$, the value $E_{cr} \lesssim 10$ volts/centimeter. The appearance of nonlinear effects is facilitated upon the attainment of resonance. Thus, in the presence of a magnetic field the nonlinearity criterion contains an additional factor $(1-\omega_H/\omega)^{-1}$ /see Note/. /Note: the existence of these nonlinearities is confirmed experimentally in the studies of O. G. Zagorodnov, Ya. D. Faynberg, B. I. Ivanov, and L. I. Bolotin (reference 44)./

As the amplitude of the excited waves increases, there appear several nonlinear effects which weaken the instability (references 45-48). Since the phase velocity of a wave depends on its amplitude, an increase in the latter will disrupt the synchronism between the beam and the wave and reduce the effectiveness of the interaction. This synchronism can likewise be disrupted by decreasing beam velocity as a result of energy losses for oscillation excitation. The reverse effect of excited oscillations on the distribution function of the beam electrons leads to a state of affairs in which the number of particles surrendering energy to the wave is reduced while the number of particles absorbing wave energy increases. This leads to a leveling of the distribution function in the region $V \simeq V_\phi$ and the termination of the instability (references 48, 45, 46). Nonlinear effects accompanying

beam-plasma interaction likewise increase beam and plasma temperature even in the absence of pair collision.

The first and third effects are significant for $V_{T_1}/V_0 \ll \delta/\omega$; and the second for $V_{T_1}/V_0 \gg \delta/\omega$.

These effects are illustrated in Table 4.

An examination of this table shows that the inclusion of nonlinear effects in calculations leads to a reduction of rise increments, the limitation of the orderly-motion velocity of the beam with a concomitant limitation on the decrease in conductivity σ ($\sigma = \frac{1}{k}$) of the plasma as a result of the transformation of orderly-motion energy into oscillatory energy, as well as an increase in beam temperature.

All of the above results are obtained in a small nonlinearity approximation, so that it is necessary to develop a theory for the case of arbitrary nonlinearity. The condition for the existence of arbitrary nonlinear periodic solutions for the case under consideration is given in reference 50. The problem of beam-plasma interaction in the case of arbitrary nonlinearity has so far been studied only from the standpoint of electron and ionic longitudinal excitations in an established regime. This examination has made it possible to determine the maximal field intensity amplitude with due regard for thermal motion and maximem field gradients proportional to the variable plasma density (see Table 5).

A consideration of Table 5 will show that the amplitude of established oscillations can reach extremely high values. For example, for a plasma density of $n \simeq 10^{15}$ and $V_\phi \simeq 10^8$, the value $E_{max} \simeq 30$ kilovolts/centimeter. There exists a maximum longitudinal wave field intensity above which we are confronted with multiple-value solutions Thus, in the one-dimensional case (without taking ionic motion into account), there can be no collision waves, so that the multiple-value of the solution apparently indicates the presence of counter current particle beams. Table 5 likewise leads to the conclusion that an increase in the number of beams leads to a reduction of the field intensity at which the subsequent beam fragmentation occurs. These effects are important in the development of new methods for plasma thermalization and the realization of CTR on the basis of counter current particle beams.

Another important problem is the study of the stability of large-amplitude longitudinal waves excited by beams. As was shown by recent studies (references 54, 55), longitudinal oscillations of large amplitude excited by a monoenergetic beam are unstable at least in relation to turbulences whose wave length is considerably smaller than that of stationary oscillations. Likewise instable are

the nonlinear solutions in the form of limited pulses excited through the interaction of beams and plasmas. Since non-linear problems are complex from the mathematical standpoint, the examination of the transition from linear oscillations to non-linear, the phenomena of spectral disintegration /see Note/, and particularly the investigation of counter current beam and stream fragmentation is most conveniently carried out with the aid of high-speed computers. The study of the process involved in counter current beam formation and plasma thermalization at high oscillatory amplitudes (references 23, 56) shows that as a result of strong interaction between individual plasma layers there arises a relative motion which in turn leads to the transformation of the initial wave energy into the energy of motion of the separate layers. The relaxation time for this process is extremely small. Thus, for example, (reference 56), if the initial oscillatory amplitude exceeds the critical amplitude by 7%, then over a period of 10 Langmuir oscillations, 70-80% of the wave motion energy is transformed into relative-motion energy. If a relatively small motion with an energy of approximately 5% of the initial energy of oscillatory motion is impressed upon the latter, then the relaxation time drops off to a single high-frequency oscillation period. Thus, the mechanism under consideration is extremely effective in tranforming the energy of regular oscillator motion into that of plasma particle motion. /Note: These phenomena consist in the fact that new waves are formed as a result of non-linear interaction between oscillations and non-parallel wave vectors; this is accompanied by a dissipation of the original-oscillation energy over a period on the order of 10^{-8} seconds (reference 76)/

The above results apply to the case of electron oscillations. Apparently, it is possible to create conditions under which analogous processes will also take place for ionic oscillations. This instance would involve an extended relative ionic motion which might be of interest in discovering methods for realizing CTR.

6) Prior to presenting an analysis of the available experimental data, let us briefly consider the question of possible methods of instability cut off, which is of the greatest importance in the given case. Research in this direction is just beginning, and for this reason the considerations given below are primarily of a qualitative character. Since instabilities in the final analysis arise as a result of the action of several basic elementary processes, as well as particle phasing or grouping which in turn leads to a considerable intensification of effects

due to the congruence phenomenon, the elimination of instabilities must proceed through the creation of conditions under which the corresponding elementary processes are impossible and particle phasing and grouping do not occur.

In order for the Cerenkov and the anomalous Doppler effects to arise it is necessary that particle or oscillator velocity be greater or equal to the phase velocity of the wave. For this reason, instability can be eliminated if this condition is violated through the alteration of wave or particle velocity. Changes in dispersive properties and, in particular, the phase velocity of the wave can be achieved by varying the geometry of a system (limited beams and plasmas), placing the plasma in a metallic jacket, making use of the dependence of phase velocity on amplitude (this effect can be used in limiting instability automatically, since increased amplitude results in an alteration of the phase velocity and a violation of synchronism between the field and beam), or by varying the relative concentration of components in the multi-component (for example, D-T, D-N) plasma.

By changing the phase velocity of the wave, it is possible to completely eliminate the instability or at least to significantly alter its frequency spectrum, as well as to reduce rise increments. By varying the beam particle velocity, it is possible to violate the condition that $V \simeq V_{\phi}$ and to completely eliminate the instability or to considerably alter the oscillation spectrum. Thus, if the particle velocity lies in the interval $V_{Ta}\mu^{1/2} < < V_0 < V_{Te}$, we encounter ionic oscillations. If the particle velocity $V_0 > V_{Te}$, then we have electron oscillations, with ionic oscillations totally absent. The beam velocity can be altered automatically in the course of its retardation. In addition to this, it is possible to effect a rapid increase in beam velocity during the relaxation time τ_{rel} during which the corresponding instabilities have insufficient time to arise. From this standpoint, the stellarator has considerable drawbacks, since the velocity of the electron beam in this system varies slowly from $v = 0$ to v_{max}, allowing for the gradual appearance of a number of instabilities. The injection of a plasma with a specified velocity into the stellarator leads to a contraction of the instability spectrum and facilitates the elimination of instabilities.

The violation of conditions allowing for the appearance of elementary Cerenkov and Doppler effects can likewise take place due to non-linear effects in the motion of particles and oscillators and non-linear effects arising in the course of wave propagation through the plasma. As

is known (reference 57), elementary processes at the basis of instabilities can be reduced to resonances between oscillations of the system proper, in this case the plasma, and the exciting force which results from the motion of charged particles and oscillators. In this case, conditions for the appearance of Cerenkov and Doppler effects are reduced to those for the appearance of resonances. The presence of the aforementioned non-linear effects leads to a violation of conditions leading to the appearance of resonances, and consequently to the elimination of instabilities. At the same time, however, we are faced with the possibility of non-linear resonances which require further study.

Another possibility for the elimination of instabilities consists in the elimination of conditions for particle phasing and grouping, which in turn lead to the appearance of coherence.

Instabilities can be weakened or even eliminated by the following methods:

1) the creation of artificial dispersion according to velocity within the beam. For purposes of illustration, let us compare the rise increments $\delta(V_{Te} = 0)$ in the case of plasma excitation by a mono-energetic beam and a beam with a weak $(V_{Te} < V_0)$ thermal dispersion δ :

$$\frac{V_{Te}}{V_0} \gg \left(\frac{n_1}{n_0}\right)^{1/3} ; \quad \delta \sim \left[\left(\frac{n_1}{n_0}\right)^{1/3} \frac{V_0}{V_{Te}}\right]^2 \delta\,(V_{Te} = 0).$$

as is obvious from these expressions, the presence of velocity dispersion can result in a considerable reduction or elimination of the rise increment [Note: it should be noted that in a number of cases a high thermal beam velocity can lead to the appearance of new instabilities with small increments];

2) preliminary beam modulation.

The exponential growth of instabilities depends, as is known, on the fact that the fields arising as a result of the instability increase the degree of particle grouping and concomitant field intensification. Preliminary modulation at a given frequency violates grouping at frequencies different from the modulation frequency, thus bringing about the elimination of an entire spectrum of instabilities. Here it is necessary to make certain that coherence conditions $a < \lambda_{pe}$ not arise to excite frequencies in the plasma proper. By modulating the beam, it is possible to eliminate an instability at a specified frequency. For this it is sufficient that the modulation wave length λ_m be equal to $\lambda_m = a/2$ [see Note]. It should be pointed out that in eliminating the usually instabilities by

modulation it is possible to bring about instabilities occasioned by parametric resonances. But since the range of parametric resonances is small, the existing inhomogeneities and collisions in real plasmas will lead to the elimination thereof. [Note: a is the length of the particle cluster];

3) alteration of the geometry of the system. As has been pointed out above, the frequency spectrum and rise increments for bounded and unbounded plasmas diverge greatly. For this reason, by altering the geometry of the system, one can alter the instability wave length to exceed the size of the system, thereby eliminating the instability;

4) reverse action by the excited oscillations on the distribution function, as a result of which the number of particles surrendering energy to the wave will equal the number of particles absorbing wave energy;

5) exploitation of the non-linear character of particle and oscillator motion;

6) alteration of the phase velocity along the system, so that $\partial V_\phi / \partial z < 0$. In actual devices, this condition can easily be realized by varying the plasma perameters such as the density. In a number of systems this can be done automatically.

A Comparison of Experimental and Theoretical Data

7) Due to the complexity of the processes involved in the interaction of charged particles with plasma and the significance of non-linear processes arising in the course of this interaction, experimental studies assume a particularly important role.

The basic aims of experimenters are the detection of instabilities, the determination of conditions under which they arise, the determination of the frequency spectrum of excited oscillations, rise increments, and relaxation periods, the measurement of energy losses in regular electron motion due to the excitation of oscillations, and the determination of the effects of instabilities on conductivity and diffusion in the plasma. An important task of experimenters is the investigation of methods for eliminating instabilities.

Experimental studies of plasma oscillations, as is known, were begun in 1921-1929 by Langmuir and Penning (reference 58). Of considerable importance in the field of oscillatory process studies in plasma are the investigations carried out in 1939 by Merrill and Webb (reference 59). The existence of instabilities connected with longi-

tudinal wave excitation in plasma in the interaction of an electron beam with a homogeneous plasma not contained in a magnetic field was experimentally proved by a number of researchers in 1957-1958. These same studies involve the measurement of basic instability characteristics.

We shall consider the general results obtained in these experiments.

The paper by I. F. Kharchenko, R. M. Nikolayev, Ye. I. Lutsenko, N. S. Pedenko, and the present author (reference 60) showed that the passage of an initially unmodulated electron beam through a plasma not contained in a magnetic field resulted in the appearance of high-frequency oscillations of frequencies close to the Langmuir values. The excitation of oscillations is accompanied by beam automodulation. Energy losses per single beam particle equal ~ 100 electron-volts/centimeter, while those for a single charged particle in the given case are just $\sim 10^{-6}$ electron-volts/centimeter. Such a sharp increase in losses is occasioned by the coherent character of beam interaction with plasma as a result of its automodulation as it excites plasma oscillations. In order to eliminate the effects of plasma inhomogeneity in these experiments, particularly boundary layers and the cathode drop region, the plasma was created by high-frequency discharge, while the electron beam was injected externally with an energy of $\sim 50 \div 70$ kiloelectron-volts; this is considerably in excess of the energy obtained by an electron in the boundary Debye layer. Initial oscillations were occasioned by fluctuations in both beam and plasma.

The work of R. A. Demirkhanov, A. K. Gevorkov, A. F. Popov, et al (reference 62) likewise revealed the excitation of longitudinal oscillations, yielded a value for the relaxation period, and established the appearance of excited wave harmonics.

The papers by M. D. Gabovich and L. L. Pasechnik (reference 63) deal with the special structure of excitation zones and the determination of beam energy losses as a result of travel through the plasma.

The effect of electromagnetic wave intensification resulting from the interaction of the beam with longitudinal waves in the plasma was discovered in the experiments of Boyd and Field (reference 64) and V. Ya. Kislov, Ye. V. Bogdanov, and Z. S. Chernov (references 65, 66). In these experiments, the initial excitation was induced by an external source, so that increasing high-frequency longitudinal waves were excited in the system. /Note: the value of the field rise increment in the space was deter-

mined with relation to signals at the input and output of the system7.

The above experiments are to some extent in conflict with those of Looney and Brown (reference 67) which did not yield the appearance of beam instabilities. The reason for this is that in their experiments Looney and Brown made use of beams with small transverse dimensions. We pointed out earlier that the oscillation rise increment decreases in direct proportion to the beam radius. The theoretically calculated value of the rise increment for the Looney and Brown experiments is equal to ~ 2.5 centimeters^{-1}. For this reason, the wave length at which the beam was to interact with the plasma (1.5 centimeters) had to increase by a factor of 10. Since in these experiments the initial excitation was detected only by means of fluctuations in the beam and plasma, the oscillation amplitude was small and hard to detect. In all of the previously mentioned experiments, however, the beam radius and interaction wave length were considerably greater. The theoretical intensification value in these experiments amounted to $\sim 10^3 \div 10^5$.

The oscillation rise increments determined experimentally and calculated theoretically are in sufficiently close agreement (Table 6). Certain discrepancies in the experimental data obtained by various authors and theoretical values is observed in determinations of the relaxation length for beam-plasma interactions, i.e., the length at which the energy of regular motion becomes oscillatory energy. A more precise comparison of experimental and theoretical data requires more accurate experimental measurements of velocity distributions in the beam and the plasma temperature, since these parameters strongly effect the relaxation length.

Experiments were carried out in 1959-1960 on the interaction of charged particle beams with plasmas enclosed in a magnetic field (I. F. Kharchenko et al, reference 68). These experiments revealed the excitation of high- and low-frequency oscillations resulting both from modulated and unmodulated beams. The spectrum of excited high-frequency oscillations is accurately described by the theoretical relationship $\omega \simeq \sqrt{\omega_0^2 + \omega_H^2}$; $\omega \simeq \omega_H$. Their intensity is particularly great if for $\omega_0 \simeq \sqrt{\omega_0^2 + \omega_H^2}$, $\omega_0 \simeq \omega_H$. Low frequency oscillations are distributed in groups in ranges of tens, hundreds, and thousands of kilocycles per second. They are distributed in the ionic-cyclotronic and magneto hydrodynamic wave regions. For a more precise determination of the types of waves excited, it is necessary to measure their

wave length ($\beta_\downarrow$) and to determine the character of the angular dependence of electromagnetic fields.

In investigating the interaction of a beam with plasma in a pulse regime, the experimentors succeeded in observing the development of instabilities by visual means and in determining their rise time due to the low frequency of the oscillations. For oscillations in the frequency range of approximately 100 kilocycles/second, the instability rise time amounts to about 50 microseconds, i.e., to about 10 oscillations (reference 49).

In addition to the excitation of the aforementioned high- and low-frequency oscillations, the experimentors likewise observed the excitation of parametric oscillations in the modulated beam.

The following is apparent from Table 6:

1) most of the instabilities considered above have by now been observed experimentally;

2) the basic instability characteristics (excitation conditions, rise increment, frequency spectra, relaxation lengths), determined experimentally are in most cases close to the theoretical values;

3) the development of instabilities is accompanied by the appearance of oscillations and a considerable reduction of the regular-motion energy of the beam. Even in the case of a rarefied plasma ($n_0 \simeq 10^{11}$), the losses amount to approximately 100 electron volts/centimeter per particle;

4) the development in instabilities likewise leads to a considerable increase in the plasma electron energy. Thus, for example, this energy reached values on the order of 10-20 kiloelectron-volts in experiments involving beam-plasma interaction in a magnetic field (reference 68);

5) the development of instabilities is accompanied by considerable increase in the ionic and electron currents perpendicular to the magnetic field.

Thus, all of the "dangerous" consequences of instabilities have been established experimentally.

At the same time, the completed experiments confirm the possibility of eliminating instabilities. Thus, for example, beam modulation leads to the elimination of an entire spectrum of instabilities due to the fact that a modulated beam can excite oscillations in the system not coinciding with the resonance wave length. Beam and plasma modulation leads to the appearance of parametric instabilities. However, since the width of excitation regions is extremely small, the density inhomogeneities in the plasma lead to the elimination of these instabilities. The elimination of a number of instabilities is achieved even with a relatively minor scattering of velo-

cities within the beam. The rise increment is highly dependent on the geometry of the system, i.e., on the beam and plasma radius, so that instabilities can also be eliminated when definite ratios between their perameters prevail. Finally a number of experiments have shown that increases in the amplitude of excited waves result in the appearance of non-linear effects which limit the development of instabilities.

The further study of the instabilities considered above and ways of eliminating them will require experiments in which the plasma density is increased to values of $n_0 \simeq 10^{13} \div 10^{14}$, with the degree of plasma ionization raised to 50-100%. In addition to this, it is necessary to significantly increase the electron current up to values of $I \simeq 10^2 \div 10^3$ a. This can be done most conveniently by using plasma formed by a powerful high-frequency discharge cesium plasma, and plasma formed in a linear betatron. It is likewise necessary to carry out experiments in which the effects of excited oscillations on conductivity and diffusion in high-frequency plasma would be determined directly.

We have been considering experiments in which the interaction between beams and plasmas was studied in specially-constructed experimental set ups designed for studying this process in its "pure" form, uncomplicated by other influences.

Of the experiments on beam-plasma interaction carried out directly in CTR installations, we should mention the work of Bernstein et al (reference 73), Ellis et al (reference 74). The most significant result of this work has been the confirmation of the fact that instabilities can arise in stellarators at currents considerably smaller than the critical currents which give rise to magneto hydrodynamic instability. These instabilities are accompanied by an increased high-frequency noise level which is considerably in excess of the "thermal" noise level. Also observed was the emission of high-frequency oscillations in the 10,000-70,000 megacycle/second frequency range corresponding to the frequency of Langmuir oscillations. By measurements of Roentgen emission it has been established that instability is accompanied by the appearance of high-energy electrons (up to 3 million electron volts). As was shown in the recent studies carried out by Ellis et al (reference 74), instabilities appear in those cases where there are proper conditions for the formation of a significant number of escaping electrons. In order for electron to achieve this state, the energy it must acquire during free-flight period must be comparable

with the thermal-motion energy ($\gamma = \frac{E}{E_{cr}} \ll 1$). In the above experiments γ turned out to be equal to 0.1-0.2. Upon attaining these values, the current in the stellarator is sharply reduced despite the increased electric field. This reduction is explained by the fact that electrons lose energy in the course of oscillatory excitation. The time during which the quantity γ reaches a critical value and the current is reduced sharply equals approximately $\sim 200 \div 800$ microseconds. The above experiments confirm the role of high-frequency instabilities in the operation of a stellarator. At the present time, however, it is difficult to evaluate the significance of high-frequency oscillations for plasma diffusion in the stellarator [see Note]. One of the drawbacks of the experiments consisted in the fact that they did not include a study of the oscillation spectrum and a correlation of these oscillations with conditions conducive to the appearance of instabilties. We must bear in mind that most of the excited frequencies are related in a simple way to the number of escaping electrons. These frequencies equal $\sim(\omega_{0e}'^2 + \omega_0^2)^{1/2} \times \omega_{0e}^{1/2}$, where ω_0 is the frequency of ionic Langmuir oscillations; ω_{0e}' is the Langmuir plasma frequency for the rest state; and ω_{0e} is the Langmuir frequency of the moving plasma [Note: low-frequency instabilities must be of great significance to diffusion in the stellarator].

8) Until the present time most of the attention in studies of beam-particle interaction was centered about the excitation of instabilities constituting one of the main obstacles in the path of realizing CTR. It is necessary to note, however, that the indicated interaction simultaneously leads to an intensive "collisionless" energy exchange between the charged particles and plasma, thereby playing a favorable role. It would be interesting to consider theoretically and experimentally the problem of using this interaction for plasma thermalization. As was pointed out above, in the interaction of electron beams with plasma, the energy of regular electron motion over a very short period of time ($\sim 10^{-6} \div 10^{-7}$ seconds) can be converted into longitudinal wave energy. As the amplitude of these waves increases, there may arise a relative electron-plasma ion motion of large relative velocity. This relative motion can also take place in the development of instabilities occasioned by transverse motion (as for example under conditions of cyclotronic resonance).

The interaction considered allows an effective transfer of energy from the electron beams to the plasma ions. For this purpose, the dimensions of the electron clusters

or the modulation wavelength a must be so selected as to satisfy the coherence conditions for ionic oscillations and not for electron oscillations. This requires that $\lambda_e < a < \lambda_i$. Under these conditions, as distinct from pair-interaction, electrons will yield most of their energy to the ions.

It is likewise possible to work out methods of injecting charged particles into plasma based on the fact that coherent losses of energy as the latter move through the plasma can attain extremely high values (100-1000 electron volts/centimeter).

Thus, beam-plasma interaction can be used for both the injection and the heating of the latter. The basic difficulty here is that this interactions allows for considerable diffusion. It should be noted, however, that there apparently exist a number of types of instabilities such as longitudinal plasma oscillations which involve large beam-plasma energy exchanges but do not directly increase diffusion.

The considerations adduced above cannot be considered fully confirmed at the present time; it is our opinion, however, that they ought to be investigated.

The interaction of charged particle beams with plasmas is likewise of interest from the standpoint of plasma diagnostics. It allows not only the determination of plasma density, but also the frequency of pair collisions in the plasma and the function of electron and ion distribution within the plasma with respect to velocity. Since in this type of interaction the oscillations rise exponentially and appear at a time when the rise increment exceeds the frequency of pair collisions, the measurement of collision frequency on the basis of the instability excitation threshold constitutes a very sensitive method indeed.

Reversing the dispersion equation, it is possible to obtain relationships connecting $f_0(v)$ with the phase and group velocities of waves propagating through the plasma, and their rise increments (reference 75). Thus, measuring the dependence of phase velocity and rise increment on frequency, it is possible to determine the distribution function for plasma particles.

Despite the importance of investigating the above problems, the question of eliminating instabilities apparently still remains the most timely and difficult task.

Expressions Used in the Present Article

$\omega_0 = \sqrt{\frac{4\pi n_0 e^2}{m}}$ -- Langmuir frequency of plasma electrons;

$\omega_{0i} = \sqrt{\frac{4\pi n_0 e^2}{M}}$ -- Langmuir frequency of plasma ions;

ω -- Frequency;

ω_H -- Langmuir frequency of electrons;

Ω_H -- Langmuir frequency of ions;

$\delta = \mathrm{Im}\,\omega$ -- Rise increment;

δ_k -- Rise increment of the wave with wave vector k;

$\Delta\omega$ -- Width of the resonance curve $\delta(\mathrm{Re}\,\omega)$;

V_ϕ -- Phase velocity of the wave in the direction of beam travel;

$k_z = \frac{\omega}{V_\phi}$ -- Projection of the wave vector on the direction of beam travel;

$k_\parallel$ -- Projection of the wave vector along the constant magnetic field;

$k_\perp$ -- Projection of the wave vector perpendicular to the constant magnetic field;

k -- Wave number;

$\mathrm{Im}\,k$ -- Rise increment in space;

V_0 -- Regularized beam velocity;

$v_\perp^0$ -- Velocity of regularized motion in a direction perpendicular to the constant magnetic field;

$V_{Te,i}$ -- Thermal velocity of electrons or ions;

V_{dr} -- Drift velocity;

V_A -- Alfven velocity;

n_0 -- Plasma density;

n_+ -- Ionic background density;

n_- -- Density of electrons not captured by the wave;

N_1 -- Number of particles in cluster;

T_{ei} -- Temperature of electrons or ions (given in ergs in the tables);

$\theta_0 = kT_e$ -- Temperature of plasma electrons for t=0 (here, k is the Boltzmann constant);

$\theta_\perp$ and $\theta_\parallel$ -- Temperature of beam electrons perpendicular and parallel to the direction of beam travel, respectively;

$\Delta\theta_\perp$ -- Variation of transverse beam temperature;

E_0 -- Intensity of constant electric field;

E_k -- Amplitude of the field of the wavecorresponding to a given value of the wave vector k;

E_{max} -- Field intensity at which beam fragmentation in the plasma begins;

E -- Electric field intensity;

$E_c \approx 1.5 \cdot 10^{-8} \frac{n_e}{T_e}$ -- Critical value of electric field intensity (volts/cm

$p_\perp, p_\parallel$ -- Momentum across and along the magnetic field;

θ -- Angle between the direction of the constant

magnetic field and the direction of wave propagation;
σ -- Conductivity;
$n_1(\omega)$ -- Refractive index;
Γ -- Gamma function;
λ_D -- Debye radius;
$\mathcal{E}$ -- Particle energy;
S -- Escaping electron stream;
a -- Radius of plasma rod;
λ -- Wavelength in vacuum;
$\mu = \frac{m}{M}$ -- Ratio of electron and ion masses;
r_i -- Larmor radius for ions;
$L_\parallel$, $L_\perp$ -- geometric dimensions of the system;

Received 28 July 1961

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Таблица 1

Неустойчивость, обусловленная эффектом Вавилова—Черенкова*

Возбуждаемые колебания	Условия возбуждения	Спектр частот	Инкремент $Im\,\omega/Re\,\omega$	Пример ($Im\,\omega$) $n_0=10^{12}$; $n_1=10^{9}$; $V_0=3\cdot10^{9}$	Литература
Продольные волны (пучок электронов малой плотности)	$V_0>V_{Te}$; $\frac{V_{Te}}{V_0}\ll\left(\frac{n_1}{n_0}\right)^{1/3}$; $\frac{V_{T_1}}{V_0}\gg\left(\frac{n_1}{n_0}\right)^{1/3}$	$\approx\omega_0$ $\sim\omega_0$	$\frac{\sqrt{3}}{2^{4/3}}\left(\frac{n_1}{n_0}\right)^{1/3}$; $\sim\frac{n_1}{n_0}\frac{V_0^2}{V_{T_1}^2}$	$4\cdot10^{8}$ *сек*$^{-1}$; $5\cdot10^{8}$ *сек*$^{-1}$	[1]
Ионно-акустические колебания	$\left(\frac{T_e}{M}\right)^{1/2}<V_0<\left(\frac{T_e}{m}\right)^{1/2}$	$k\left(\frac{T_e}{M}\right)^{1/2}\times$ $\times(1+k^2\lambda_D^2)^{-1/2}$	$Im\,\omega=\omega_{0i}\times$ $\times\frac{V_0-\left(\frac{2T_e}{3M}\right)^{1/2}}{2V_{Te}}$	$2\cdot10^{8}$ *сек*$^{-1}$; $V_0=\frac{V_{Te}}{3}=10^{8}$	[7] [11]
Ионно-акустические колебания в магнитном поле	»	$k\left(\frac{T_e}{M}\right)^{1/2}\times$ $\times\left[1+k_{\parallel}^2\lambda_D^2+k_{\perp}^2\frac{T_e}{T_i}\right]^{-1/2}$	»	»	[12]
Альфвеновские волны	а) обыкновенная волна: $V_0^2>V_A^2\left(1+\frac{n_0}{n_1}\right)$; б) необыкновенная волна: $V_0^2\cos^2\theta>V_A^2\left(1+\frac{n_0}{n_1}\right)$	$\sim kV_A\cos\theta$; $\sim kV_A$	$\left[\frac{V_0^2}{V_A^2}-1-\frac{n_0}{n_1}\right]^{1/2}$; $\left[\frac{V_0^2}{V_A^2}\cos^2\theta-1-\frac{n_0}{n_1}\right]^{1/2}$		[13] [14] [15] [16]
Продольные волны в магнитном поле (пучок электронов $\omega_H\Omega_H<\omega_0^2\ll\omega_H^2$; $\theta\neq\frac{\pi}{2}$)	$k_zV_0=\omega_e\,\lvert\cos\theta\rvert$; $\omega_H<k_zV_0<\sqrt{\omega_H^2+\omega_0^2\cos^2\theta}$	$\sqrt{\omega_H^2+\omega_0^2\sin^2\theta}$; $\omega_e\,\lvert\cos\theta\rvert$;	$\frac{\sqrt{3}}{2^{4/3}}\left(\frac{\omega_i^2\omega_0^2}{\omega_H^4}\,\mathrm{ctg}^2\theta\right)^{1/3}$; $\frac{\sqrt{3}}{2^{4/3}}\left(\frac{n_1}{n_0}\right)^{1/3}$		[15] [16]

* T—температура в эргах.

A Продолжение табл. 1

Возбуждаемые колебания B	Условия возбуждения C	Спектр частот D	Инкремент $Im\omega/Re\omega$ E	Пример ($Im\omega$) $n_0=10^{12}$; $n_1=10^8$; $V_0=3\cdot10^9$ F	Литература G
H Продольные волны поперек магнитного поля (пучок ионов; $\omega_0^2 \gg \omega_H^2$; $\theta \simeq \frac{\pi}{2}$)	$k_z V_0 \simeq (\omega_H \Omega_H)^{1/2}$	$(\omega_H \Omega_H)^{1/2}$	$\frac{\sqrt{3}}{2^{4/3}} \left(\frac{n_1}{n_0}\right)^{1/3}$	$3\cdot10^7$ $сек^{-1}$	[17]
I Магнитозвуковые волны ($n_1 \ll \mu n_0$)	$V_{Ti} < V_0 < S$; $V_A < V_0 < V_{Te}$	kV_A	$\left(\frac{n_1 \cos^2\theta}{\mu n_0}\right)^{1/2}$	$n_1 = 10^4$; $6\cdot10^4$ $сек^{-1}$	[18] [19]
J Неустойчивость в неоднородной плазме	$\frac{\partial \ln T_0}{\partial \ln H_0} > 1$	kV_{H0}	—	—	[9]
K Неустойчивость ионного пучка в плазме	$\left(\frac{n_1}{n_0}\right)^{1/3} \frac{V_0}{V_{Te}} \geqslant 1$	kV_0	~ 1	—	[20]
L Продольные колебания в электронно-ионных пучках	$\|V_{e0}\| > \|V_{i0}\| + V_{Te} + V_{Ti}$; $\|V_{i0}\| > \|V_{e0}\| + V_{Te} + V_{Ti}$; $\|V_{e0}\| > V_\phi + V_{Te}$; $\|V_{i0}\| > V_\phi + V_{Ti}$	—	—	—	[21]

A = Continuation of Table 1;
B = Excited oscillations;
C = Excitation conditions;
D = Frequency spectrum;
E = Increment;
F = Example;
G = References;
H = Longitudinal waves across the magnetic field (ion beam);
I = Magnetic-sound waves;
J = Instabilities in a non-homogeneous plasma;
K = Instability of an ionic beam in plasma;
L = Longitudinal oscillations in electron-ion beams.

A Неустойчивость при аномальном эффекте Доплера

Таблица 2

Вид колебаний B	Условия возбуждения C	D Спектр частот	E Инкременты нарастания $Im\omega/Re\omega$	Числовой пример ($Im\omega$) $n_0=10^{12}$; $n_1=10^{9}$; $H_0=10^3$; $V_0=3\cdot10^9$ F	G Литература
H Неустойчивость поперечных волн в электронном пучке	$\omega+\omega_H \simeq k_3V_0$; $\omega_0^2 \gg \omega_H^2$	$\omega < \omega_H$	$\frac{\omega_1}{\omega_0}\left\lvert \frac{\omega_H}{\omega} - 1 \right\rvert$	$3\cdot10^8$ *сек*$^{-1}$	[22]
I Продольные колебания (два пучка)	$k_3V_{01} \simeq \frac{\omega_{02}}{1-V_{02}/V_{01}}$	$\omega \simeq \frac{\omega_{02}}{1-\frac{V_{02}}{V_{01}}}$	$\frac{\sqrt{3}}{2^{4/3}}\left(\frac{n_1}{n_2}\right)^{1/3}\left(1-\frac{V_{02}}{V_{01}}\right)^{-2/3}$	$\sim 4\cdot10^9$ *сек*$^{-1}$	[5; 6]
J Продольные электронно-ионные колебания (электроны плазмы образуют пучок)	$\omega_0 \simeq k_3V_0$	$\sim \omega_0\mu^{1/3}$	$\sqrt{3}$	$5\cdot10^9$ *сек*$^{-1}$	[23, 79]
Продольные колебания (электроны плазмы образуют пучок) K	$V_\phi \gg V_T$	$\omega \ll k_3V_0$	$Im\omega \simeq \mu^{1/2}\omega_0$	$1{,}5\cdot10^9$ *сек*$^{-1}$	[24]
Ионно-циклотронные колебания, возбуждаемые электронным пучком L	$\omega_H \simeq k_3V_0$	$\sim\Omega_H$	$\frac{\omega_1}{2\omega_0}\frac{V_0^2}{V_A^2}\mu(1+\cos^2\theta)$	$3\cdot10^4$ *сек*$^{-1}$	[17, 15]
Ионно-циклотронные колебания, возбуждаемые ионным пучком M	$2\Omega_H = k_3V_0$; $V_0 < V_A$	$\sim\Omega_H$	$\frac{\omega_1}{8\omega_0}\frac{V_0^2\sin^2\theta}{V_A^2}$	$V_0 = 10^8$ *см/сек*; $8\cdot10^6$ *сек*$^{-1}$	[16]
Колебания плазмы поперек магнитного поля, возбуждаемые электронным пучком N	$\omega_H \simeq k_3V_0$; $\theta = \frac{\pi}{2}$; $\omega_0^2 \gg \omega_H^2$	$\sim\sqrt{\omega_H\Omega_H}$	$\frac{\omega_1}{2\omega_0}\left(\frac{m}{M}\right)^{1/4}$	$4\cdot10^7$ *сек*$^{-1}$	[17]
O Продольные электронные колебания, возбуждаемые электронным пучком	$\omega_H \simeq k_3V_0$; $\theta \neq \frac{\pi}{2}$; $\omega_0^2 \ll \omega_H^2$	$\omega_+ \simeq \sqrt{\omega_H^2+\omega_0^2\sin^2\theta}$; $\omega_- \simeq \omega_0\cos\theta$	$\frac{\omega_1\omega_0}{2\omega_H^2}\sin^2\theta$; $\frac{\omega_1}{2(\omega_0\omega_H)^{1/2}}\frac{\sin\theta}{\sqrt{\lvert\cos\theta\rvert}}$		[15]

Table 2

A = Instability occasioned by anomalous Doppler effect;
B = Type of oscillations;
C = Excitation conditions;
D = Frequency spectrum;
E = Rise increments;
F = Numerical example;
G = References;
H = Instability of transverse waves in electron beam;
I = Longitudinal waves (two beams);
J = Longitudinal electron-ion oscillations (plasma electrons form a beam);
K = Longitudinal oscillations (plasma electrons form beam);
L = Ionic-cyclotronic oscillations excited by electron beam;
M = Ionic-cyclotronic oscillations excited by ion beam;
N = Plasma oscillations across magnetic field excited by electron beam;
O = Longitudinal electron oscillations excited by electron beam;

Таблица 3

A Неустойчивость при нормальном эффекте Доплера

Вид неустойчивости B	Условия возбуждения C	D Частоты	E Инкремент нарастания $\mathrm{Im}\,\omega/\mathrm{Re}\,\omega$	F Пример $\mathrm{Im}\,\omega$	Литература G
Неустойчивость электронного пучка осцилляторов $[f_e = \delta(v_\parallel)\,\delta(v_\perp - v_\perp^0)]$ H	$k_\perp v_\perp^0 \simeq \omega_H;\ \theta = \frac{\pi}{2}$; $k_\perp v_\perp^0 \leqslant \omega_H;\ \theta \neq \frac{\pi}{2}$	$\omega \sim n\omega_H$; $n = \pm 1;\ \pm 2$	~ 1	—	[25]* [27]
I Неустойчивость поперечных волн, взаимодействующих с релятивистским потоком осцилляторов $[f_e = \delta(p_\parallel - p_\parallel^0)\,\delta(p_\perp - p_\perp^0)]$	$\omega(1-\beta_\perp^2) < k_\parallel V_0$; $\left(\beta_\perp = \frac{v_\perp}{c}\right)$; $\theta = 0$	$\omega = \frac{ck}{n_j} \simeq kV_0 - \omega_H$	$\sim \left\{ \frac{\omega_1^2}{\omega} \frac{\frac{kV_0}{\omega} + \beta_\perp^2 - 1}{\frac{d}{d\omega}\left(\omega^2 n_j[(\omega)]\right)} \right\}^{1/2}$	—	[22]
J Неустойчивость ионного пучка осцилляторов $f_1 = \delta(v_\parallel)\,\delta(v_\perp - v_\perp^0)$	$a_i = \frac{k_\perp v_\perp^0}{\Omega_H} \leqslant 1;\ \theta \neq \frac{\pi}{2}$; $V_\perp^0 \gg V_{Te}$	$\omega \simeq n\Omega_H$; $n = 1$	$\sim \left[\frac{v_\perp^{02}}{V_A^2} \left(\frac{I_n^2(a)}{a^2} + \frac{\cos^2\theta - i_n^2(a)}{n^2} \right) + \mu I_n^2(a) \right]^{1/2}$	$v_\perp^0 = 10^8;\ n_1 = 10^8$; $H_0 = 10^3$; $2\cdot 10^5\ сек^{-1}$ (sec⁻¹)	[28]
K Возбуждение продольных колебаний в плазме электронным пучком осцилляторов	$a_e = \frac{kv_\perp^0}{\omega_H} \leqslant 1$; $V_\parallel^0 \gg V_{Te}$	$\omega_+ \simeq \sqrt{\omega_H^2 + \omega_0^2 \sin^2\theta}$ $(\omega_0^2 \ll \omega_H^2)$; $\sim k_\parallel v_0 + n\omega_H$; $\omega \sim \omega_0 \mid\cos\theta\mid$	$\frac{\delta_1}{\omega_+} \simeq 0{,}4 \left(\frac{n_1}{n_0} a_e^2 \frac{\omega_0^6}{\omega_H^4} \sin^2\theta \cos^2\theta \right)^{1/3}$ $(n = 1)$; $\frac{\delta_2}{\omega_+} = 0{,}4 a_e^{2/3} \frac{\delta_1}{\omega_+}$ $(n = 2)$; $\frac{\delta_1}{\omega_-} \simeq 0{,}4 \left(\frac{n_1}{n_0} a_e^2 \right)^{1/3}$ $(n = 1)$; $\frac{\delta_2}{\omega_-} \simeq 0{,}4 a_e^{2/3} \frac{\delta_1}{\omega_-}$ $(n = 2)$	$n_0 = 10^{12};\ n_1 = 10^9$; $H_0 = 10^4;\ a_e = 0{,}1$; $\delta_1 \simeq 2\cdot 10^8\ сек^{-1}$; $\delta_2 \simeq 1{,}6\cdot 10^7\ сек^{-1}$ (sec⁻¹)	[29] [30]

L * Неустойчивость функции распределения в отсутствие пучков, обусловленная анизотропией температур, была установлена и исследована Р. З. Сагдеевым, Л. И. Рудаковым, А. А. Веденовым [25], а также Розенблютом [78].

Table 3

A = Instability occasioned by normal Doppler effect;
B = Type of instability;
C = Excitation conditions;
D = Frequencies;
E = Rise increment;
F = Example;
G = References;
H = Instability of oscillator electron beam;
I = Instability of transverse waves interacting with relativistic oscillator stream;
J = Instability of ionic oscillator beam;
K = Excitation of longitudinal oscillations in plasma by electron oscillator beam.

Таблица 4

A Нелинейные эффекты при взаимодействии пучка с плазмой

Тип взаимодействия B	Торможение пучка C (ΔV)	Рост температуры D ($\theta_\parallel$; $\theta_\perp$)	Время релаксации E ($\tau_{рел}$)	Инкремент F (δ_k)	$V_\varphi(K)$	Литература* G
H Электронный пучок в ионной плазме ($E_e > E_{кр}$; $\mu M = m$; $E_q = e n_e^{2/3}$; $\lambda_D^3 E_D = e$; $\tau = \omega_p t$)	$V_e \frac{\theta_e}{\theta_\perp}\left(\frac{E_q}{E_e}\right)^3 \times$ $\times \frac{e^{\alpha\tau}}{\alpha\tau^{5/2}}$; $\alpha = 0{,}05$	$\theta_\parallel = \theta_e\left(\frac{E_q}{E_e}\right)^2 \frac{e^{\alpha\tau}}{\tau^{7/2}}$; $\theta_\perp = \theta_e\left(\frac{E_D e^{\alpha\tau}}{E_e \tau^{3/2}}\right)^{1/2}$	$\frac{1}{\alpha\omega_e} \ln\left(\frac{\theta_\perp}{\theta_e} \times \times \frac{E_q^2}{E_e^2} \alpha^{-5/2}\right)$	—	$V_{e}\mu^{1/2} 2^{-4/2} \times$ $\times\left(1 + \frac{21}{16} \times \times \frac{2^{1/2} e^2 E_k^2 V_e}{m^2 V_e^3 \omega_p \mu^{1/2}}\right)$.	[23]; [45]
Моноэнергетический пучок в плазме I $\left(\frac{V_{T1}}{V_e} \ll \mathscr{E} = \left(\frac{n_1}{n_e}\right)^{1/2}\right.$; $\left.\omega_p t = \tau\right)$	—	$\theta_\parallel = \frac{\mathscr{E}^{1/2}\theta_e \omega_e^5 d^2}{15 n_e V_e^2} \times$ $\times\left(1 + \frac{\mathscr{E} m V_e^2}{\theta_e}\right) \frac{e^{\mathscr{E}\tau}}{\tau^{3/2}}$	$\frac{1}{\omega_e \mathscr{E}} \ln \times$ $\times\left(\frac{m V_e^2}{\theta_e + \mathscr{E} m V_e^2} \times \times \frac{n_e V_e^5 \tau^6}{\omega_e^2 d^2} \mathscr{E}^{2/2}\right)$	$\mathscr{E}\omega_e\left(1 - \frac{e^2 E_k^2 F}{8 \mathscr{E}^3 m^2 V_e^2 \omega_e^2}\right)$	$V_e\left(1 - \mathscr{E} 2^{-4/2} - \frac{5}{8} \frac{e^2 E_k^2 F}{\mathscr{E}^2 m^2 V_e^2 \omega_e^2}\right)$	[46]; [47]
J Ионно-звуковые колебания (монохроматическая волна)	—	$\theta_i \sim \frac{e^2 E_k^2}{M\omega^2} e^{2\int \delta_k dt}$	—	$\frac{\delta_k(t)}{\delta_k(0)} \simeq \exp \times$ $\times\left\{-\frac{e^2 E_k^2 k^2}{m^2} \times \times \int_0^t \frac{d\tau}{\delta_k^2} \exp \times \times\left[2 \int_0^\tau \delta_k d\tau'\right]\right\}$,	—	[48]; [45]
K Высокочастотные колебания электронного пучка с плазмой ($\omega = -\omega_H + k_\parallel V_e$)	$\frac{\Delta\theta_\perp}{m V_e}$	$\frac{\Delta\theta_\perp}{\theta_e} = \frac{3\sqrt{2}}{\pi} \frac{\omega_H^2}{n_1 V_e^2} \times$ $\times \frac{1}{\tau} \exp\left[\frac{5}{8} \times \times\left(\frac{\omega_e}{\omega_H} \frac{n_1}{n_e}\right)^{1/2} \tau\right]$	—	—	—	[49]

* $F = \exp\left\{2 \int_0^t \delta_k dt\right\}$

Table 4

A = Nonlinear effects in beam-plasma interactions;
B = Type of interaction;
C = Beam retardation;
D = Temperature rise;
E = Relaxation time;
F = Increment;
G = References;
H = Electron beam in ionic plasma;
I = Monoenergetic beam in plasma;
J = Ionic-sonic oscillations (monochromatic wave);
K = High-frequency electron beam-plasma oscillations;

Таблица 5

A Взаимодействие пучков с плазмой в случае произвольной нелинейности

B Тип взаимодействия	$E^2_{макс} = E^2_{max}$	$\left(\frac{dE}{dx}\right)_{макс = max}$	C Пример ($V_0=10^9$; $n_0=10^9$; $n_\pm=10^{11}$)	D Литература
Электронные колебания в плазме E	$4\pi n_+ m V_\Phi^2\left[1-\left(\frac{8V_T}{\pi V_\Phi}\right)^{1/2}\frac{n_-}{n_+}\Gamma\left(\frac{3}{4}\right)\right]$	$4\pi n_+ e\left(\frac{V_0}{2\pi V_\Phi}\right)^{1/2}\frac{n_-}{n_+}\Gamma\left(\frac{1}{4}\right)$	$V_\Phi=1{,}1\cdot10^9$ $V_T=10$ $E\approx10^4\frac{V}{см}$	[51]
Электронные колебания в плазме с пучком F	$4\pi m(V_0-V_\Phi)^2\times\left[n_1-n_-\frac{V_T}{2\sqrt{\pi}V_\Phi}\left(1-\frac{V_0}{V_\Phi}\right)^2\right]$	∞	$E\approx100\frac{V}{см}$	[51]
Ионные колебания G	$4\pi M V_\Phi^2 n_+$	∞	$E\approx10^4\frac{V}{см}(V_\Phi=3\cdot10^7)$	[52, 53]

Table 5

A = Beam-plasma interaction in the case of arbitrary nonlinearity;
B = Type of interaction;
C = Example;
D = References;
E = Electron oscillations in plasma;
F = Electron oscillations in plasma with beam;
G = Ion oscillations.

Таблица 6

A Сравнение теоретических и экспериментальных значений инкрементов нарастания и длин релаксаций

Вид колебаний B	Частота C	D Инкремент нарастания: E эксперимент	Инкремент нарастания: F теория	G Длина релаксации: H эксперимент	Длина релаксации: I теория	J Литература
Усиление плазмой продольных волн в пучке K	$\sim \omega_0$ $(2 \cdot 10^{10})$	—	—	—	—	[64]
Возбуждение пучком продольных волн в плазме L	$\sim \omega_0$ $(2 \cdot 10^{10})$	$Im\,\omega \approx 0{,}16\omega_0$	$Im\,\omega \approx 0{,}15\omega_0$	$\frac{d\xi}{dx} \approx 50\,\frac{eV}{см}$ (cm)	$\frac{d\xi}{dx} \approx 100\,\frac{eV}{см}$ (cm)	[60]
Усиление плазмой продольных волн в пучке M	$\sim \omega_0$ $(2 \cdot 10^{10})$	$Imk \approx 0{,}2\ см^{-1}$ (cm^{-1})	$Imk \approx 0{,}15\ см^{-1}$ (cm^{-1})	—	—	[65]
Возбуждение пучком продольных волн в плазме N	$\sim \omega_0$ $(1{,}5 \cdot 10^{10})$	$Imk \approx 0{,}12\ см^{-1}$ (cm^{-1})	$Imk \approx 0{,}15\ см^{-1}$ (cm^{-1})	7 см (cm)	8,4 см	[61]
Рассеяние пучка на колебаниях плазмы O	$\sim \omega_0$ $3 \cdot 10^{9} \div 3 \cdot 10^{10}$	—	—	1 см (cm)	4—10 см	[63]
Высокочастотные колебания в магнитном поле P	$\omega \approx \omega_H\ (10^{10})$; $\omega \approx (\omega_0^2 + \omega_H^2)^{1/2}$ $(2 \div 4 \cdot 10^{10})$	$1 \div 2 \cdot 10^{8}$; $1 \div 2 \cdot 10^{9}$	$0{,}5 \cdot 10^{9}$	—	—	[63]
Низкочастотные колебания в магнитном поле Q	$\sim (6 \div 120) \cdot 10^{3}$; $\sim \Omega_H\,(6 \div 30) \cdot 10^{6}$	$1 \div 20 \cdot 10^{3}$ $(n0^{\Delta\omega/\omega})$	—	$\delta_{рел} \approx 5 \cdot 10^{-6}$ δ_{te} C	—	[68]
Высокочастотные колебания в магнитном поле R	$\sim \omega_H\,(4{,}2 \cdot 10^{9})$; $\sim (\omega_0^2 + \omega_H^2)^{1/2}$	$\sim 10^{8}$	—	—	—	[69]
То же S	$\omega_H < \omega < (\omega_0^2 + \omega_H^2)^{1/2}$	$Imk \approx 0{,}7$ $(\omega \approx \omega_0)$	$Imk \approx 0{,}7$ $(\omega \approx \omega_0)$	—	—	[70]
T Низкочастотные ионные колебания	$\omega \approx 8 \cdot 10^{5}$ $(\sim \omega_{0i})$	—	—	—	—	[71]
Высокочастотные U колебания в магнитном поле	$\omega \approx 1 \div 2 \cdot 10^{9}$	—	—	—	—	[72]*

*Автор признателен С. Д. Винтеру за возможность ознакомиться с этой работой. V

Table 6

A = Comparison of theoretical and experimental values for rise increments and relaxation lengths;
B = Type of oscillation;
C = Frequency;
D = Rise increment;
E = Experiment;
F = Theory;
G = Relaxation length;
H = Experiment;
I = Theory;
J = References;
K = Intensification of longitudinal waves in beam by plasma;
L = Excitation of longitudinal waves in plasma by beam;
M = Intensification of longitudinal waves in beam by plasma;
N = Excitation of longitudinal waves in plasma by beam;
O = Beam diffusion at plasma oscillations;
P = High-frequency oscillations in magnetic field;
Q = Low-frequency oscillations in magnetic field;
R = High-frequency oscillations in magnetic field;
S = Same as (R) above;
T = Low-frequency ion oscillations;
U = High-frequency oscillations in magnetic field;
V = The author is grateful to D. Vinter for the opportunity to acquaint himself with this work.

MAGNETIC TRAPS WITH CUSPED FIELDS

/Following is the translation of an article by S. Yu. Luk'yanov and I. M. Todgornyy in Atomnaya Energiya (Atomic Energy), volume 11, # 4, October 1961, pps. 336-344./

Introduction

In the search for systems suitable for the experimental realization of thermo-nuclear synthesis, there have been several installations of extreme interest from the standpoint of originality and engineering ingenuity. Seeking to find a final or penultimate solution to a most difficult technical problem, physicists have been obliged to construct systems on a very large scale capable of achieving a high state of vacuum and producing magnetic fields in complex configurations. Such installations as the "Ogra", "Zelta", or the stellarator serve as clear testimony of the trends followed in the construction of such devices.

Unfortunately, the real properties of heated plasma are considerably more complex than is pictured in idealized representations. They exhibit various types of irregularities which have been detected just recently in magnetic traps with plugs and toroidal systems with longitudinal magnetic fields. This makes quite clear the re-awakened interest in traps with magnetic fields increasing toward the periphery, which, at least in principle, are free from certain of the irregularities. Another advantage of these traps is the absence of a magnetic field in the central region, i.e., in the area of maximum plasma concentration. This leads to a situation where magnetic radiation losses become insignificant. There is little need for placing special empnasis on this fact with the present level of our knowledge, however. We are still very far from attaining conditions under

which magnetic radiation losses are a serious obstacle in the construction of a thermonuclear generator.

Quite naturally the aforementioned advantages are not secured free of charge. A trap with an increasing magnetic field turns out to be extremely full of holes. In addition to the possible loss of particles through the floods near the access of the system, traps of this type have an annular magnetic crack in their equatorial plane of symmetry. (It is assumed that the trap is axially symmetric and is made up of 2 spools facing one another, i.e., constitutes a magnetic quadropole.)

As has been the case in almost all of the main research trends concerned with the problems of directed synthesis, the first ideas and suppositions were expressed both in the Soviet Union and abroad completely independently and practically at the same time. The general properties of magnetic systems in which the upper boundary of the plasma is convex were established by L. A. Artsimovich and E. Teller. Just prior to the Second International Conference on the Peaceful Uses of Atomic Energy (Geneva, 1958), O. B. Firsov (reference 1) of the Soviet Union, and Grad, Berkowich, and others (reference 2) from the west, had already examined the process of plasma leakage from the region bounded by the increasing field. In particular, O. B. Firsov proposed the idea of the diffusive expansion of the magnetic fissure so characteristic of this type of trap. At the same time, discussions were held at the Atomic Energy Institute of the USSR Academy of Sciences to consider the experimental possibilities of constructing a small stationary trap of this type; these talks were followed by the first experiments (references 3, 7). This same period saw the appearance of papers dealing with the passage of plasma clots through magnetic fields of various configurations, including fields of increasing intensity toward the periphery (reference 4), as well as articles concerned with the behavior of weakly-ionized plasmas in such fields (reference 5). On the whole, however, developments in this field were rather slow in coming and the aforementioned re-awakening of interest in traps with cusped fields has taken place just within the last 1 or 2 years. It was during this time that American and Soviet periodicals published about 10 articles dealing with the behavior of plasmas in such setups (references 6-16). Nevertheless, the accretion of data so far obtained is quite small, with many problems requiring further detailed investigation, so that a logical presentation of the accumulated experimental information presents serious

difficulties.

We shall make use of the following outline in the presentation of our material: first, we shall examine the qualitative picture of plasma behavior in a trap, then proceeding to discuss the basic experimental facts, concluding with a few remarks concerning possible future research trends.

Plasma Behavior In A Cusped-Field Trap

Let a magnetic system be made up of 2 coaxial coils aligned in a face to face configuration (figure 1); then in the neighborhood of the null field point, the magnetic field components will increase liniarly with the co-ordinate:

$$H_z = aZ \; ; \; H_r = -\frac{a}{2}r \qquad (1)$$

Let us suppose that with the aid of some unknown mechanism, a hot and highly conductive plasma is briefly introduced precisely into the center of the trap where $H = 0$. The plasma then pushes the lines of force apart and fills in the weak field region. This gives rise to a central region free of any field and a compressed field region without any plasma (figure 2a,b). A pressure balance is established at the plasma boundary, corresponding currents flow along the plasma surface, and the diamagnetic plasma formation has an unchanging, stable form. At this initial moment of time, plasma leakage takes place through an annular magnetic fissure of width $4\rho_e$; here ρ_e is larmor radius for electrons in the area of the fissure. Simultaneously with plasma leakage, however, there begins yet another process in which the plasma gradually starts to diffuse into the field and the field gradually enters the plasma; this is a mutual interpenetration of plasma and field. This process can also be characterized as an expansion of the magnetic fissure. According to the laws of diffusion, the increase in the size of the fissure is very rapid at first, but slows down gradually (figure 2c,d). Penetrating into the transition layer, the plasma escapes from the trap through the expanded annular fissure, moving along the force field lines. As a result of quasi-neutrality, the leakage of plasma in this direction proceeds at ionic rates. At the boundary between the "pure" plasma and the transition layer there is a pressure equilibrium, and the plasma is ejected from the trap like toothpaste from a tube. It

turns out that if a pressure equilibrium does indeed exist the rate of fissure (or transition layer) expansion is independent of the magnetic field and is equal to the skin layer formation rate.

In order to understand what follows, it must be noted that the debye screening radius at the plasma boundary is much less than the larmor ionic radius. For this reason, the formation of a transition layer which takes place as a result of electron-ionic collisions starts at the layer whose thickness at the first moment is equal to the larmor electron diameter. Speaking pictorially, mobile electrons strive to escape from the trap along the lines of force (through the fissures) but are held back by slow ions. It would seem that the field would be traversed in a transverse direction by ions with large larmor radii, but these are held back by electrons.

Within the framework of this qualitative picture it is possible to determine the dependence of the time of plasma seepage from the trap on the characteristic size of the system R, the magnitude of the magnetic field H, and the initial plasma energy W, as well as to investigate the character of plasma density variation with time.

Appropriate calculations (reference 16) show that the time of plasma life within the trap under these conditions is approximately proportional to the expression $(R/H)^{1/2}$, slowly increasing with the initial energy of the plasma formation and practically independent of plasma temperature.

To find the dependence of plasma density on time, it is necessary to solve an equation of the form

$$\frac{dN}{dt} = -\frac{n v_i}{4} S \qquad (2)$$

where N is the total number of particles in a field-free region; n is the plasma density; v_i is the ionic velocity and S is the magnetic fissure area. Taking the classical expression for the diffusion coefficient and noting that $N = nV$ where V is the variable volume of the compressed plasma, and making use of the condition that the plasma and field pressures are equal, it is possible to find the solution to the above equation. Figure 3 depicts the variation of plasma temperature with time. The salient feature of the solution is the fact that the plasma escapes from the trap within a definite time, and not that density decreases according to an expanential law.

Of course, everything said so far hardly describes the actual processes which take place in a trap. The

fact of the matter is that the behavior of plasma in such a trap, its stability, length of life, etc., are all closely bound up with the method of plasma injection.

Almost all researchers concerned with cusped-field traps make use of some variation of electro-dynamic injectors in their work. Various types of injectors vary significantly with respect to intensity, the rate of motion of the plasma clot, and time of operation. There is no such thing is an ideal injector, however, which could introduce extremely hot plasma into the trap within a very short period of time. For this reason, in penetrating the magnetic barrier under actual working conditions, the plasma already partially mingles with the field (figure 4). The depth of field penetration into the plasma, the magnitude of the magnetic stream caught up by the plasma and "frozen" into it are dependent on plasma temperature, the rate of its motion, and the magnitute of the magnetic barrier. We must note 2 conditions which accompany the filling of the trap with plasma. In the first place, the filling process proceeds simultaneously with the expansion of the magnetic fissure and plasma diffusion in all directions. In other words, plasma density increases as the plasma seeps off. In the second place, the presence of a macroscopic current flowing along the periphery of the plasma clot being injected acts to displace the center of the system (the point of null field in a vacuum) somewhat.

The process of field-free plasma seepage from the trap (if such plasma does indeed exist) is again described by equation (1) but with an additional term which depends on time and takes the action of the injector into account. The seepage time in this case is finite.

Let us now assume that by the end of the injection process there will be a certain volume within the trap filled with field-mixed plasma. Let us also assume that "pure" plasma constitutes a small portion thereof. Then the process of trap emptying is best described with the aid of a model with a constant volume and a fissure of constant width. Let us recall that the fissure width increases rapidly during the initial stages, and, consequently, having reached significant proportions by the time of the injection, continues to increase in size quite slowly. In the central portion of the weak field, the ions are as formerly unmagnetized, so that their movement from one edge of the fissure to the other proceeds without the conservation of magnetic moment. Plasma seepage as formerly takes place along the lines of force at an ionic rate but without additional pressure applied by a

magnetic field. In such a model, the variation of plasma density with time can be written as

$$n = n_0 e^{-t/\tau} \tag{3}$$

where τ is the characteristic seepage time (figure 5). The value τ is given by the equation

$$\tau = \frac{2R}{v_i}\left(\ln R/\delta + 1\right) \tag{4}$$

where δ is the fissure width, and the rest of the symbols as defined above.

Hence, regardless of the concrete model considered, the plasma in traps with cusped-fields will be concentrated in the central region. Plasma seepage must take place through the annular magnetic fissure. The time of plasma escape from the trap can be determined for two boundary cases. In the model with "pure" plasma, the seepage time turns out to be finite.

Basic Experimental Data

Table 1 contains a listing of the sizes and maximum values for the magnetic field (in the region of the magnetic fissure) for a number of completed setups. In all systems with the exception of that of Watteau, the plasma is introduced into the trap along the axis of symmetry with the aid of an electro-dynamic injector of some type. The directed velocity of the plasma clot lies within the limits of $(0.7-1.2)\cdot 10^7$ centimeters/second. In the Watteau /reference 9/ setup, the variable magnetic field with a period of 10 microseconds and an amplitude as indicated in Table 1 was applied to a direct self-constricting charge with a current intensity of 15 kiloamperes. Vacuum conditions were comprable in all cases. Ultra-high vacuum techniques were not employed.

A number of methods were employed in the study of plasma behavior in the trap. Photographic techniques, including high speed photography were used to obtain photographs of the plasma in the traps at various moments of time. The use of electrical probes of various types made it possible to determine plasma density as it varied in time and its topography. Magnetic probes were employed to study the process of field displacement (or capture)

in the plasma and for determining the currents flowing through the injected plasma clots. Calorimetric methods made it possible to determine the spatial picture of plasma seepage from the central regions of the trap. Spectroscopic techniques were employed quite sparingly. This was partially due to the low intensity of luminescence from the plasma under the given conditions.

Let us first consider the experimental data confirming the capture of plasma clots in traps and the problem of plasma life. Figure 6 shows oscillograms of ionic saturation current on an electric probe placed in the central region obtained in the "Orekh" (reference 16). Assuming constant plasma temperature, these curves indicate the variation of its density with time. The discharge in the injector circuit is cut off with the aid of a special discharger following the first semi-period; thus, the duration of the entire cycle is about 3 microseconds. As may be seen from the oscillograms, plasma density reaches a maximum value after the current is cut off in the injector circuit. The process of density decrease is stretched out over many tens of microseconds. It is interesting to note that the characteristic seepage time turns out to be practically independent of the strength of the magnetic field. Figure 7 illustrates this contention with the aid of data obtained with the same trap.

Plasma lifetimes as measured with other setups turn out to be on the same order and lie within limits ranging from ~15

microseconds in reference (9) up to ~200 microseconds in reference (12). Another factor to be taken into consideration in the latter case is the extremely long duration of the injection process (~150 microseconds), making it difficult to distinguish the trap filling stage from the leakage stage. Another complicating factor in this particular experiment is secondary ionic emission from the walls of the system which supplies slow ions to the central region and lengthens the plasma disintegration process.

The process of plasma formation and disintegration can likewise be observed through variations in its luminescence, registering the intensity with the aid of a photoelectric pickup. The results of photoelectric

measurements are in agreement with data obtained with the aid of probe techniques.

The experiment in reference 11 involved the use of high-speed motion picture photography for observing the course of the process. The resulting films make it possible to follow both the penetration of the plasma through the magnetic barrier and its subsequent behavior within the trap. In this case, the plasma life time was likewise on the order of tens of microseconds.

In summary it might be said that the combination of probe, photoelectric and photographic observations is sufficiently convincing testimony of plasma clot capture in the trap. The characteristic plasma lifetimes turn out to be rather discouraging, however; they are quite close to flythrough times. This is not surprising; as has already been stated, in traps with cusped fields the plasma can escape through fissures without being retarded by collisions between particles.

Quantitative comparisons of experimental data with the above estimates are of course of a preliminary character. Let us nevertheless cite a few figures. For the "Orekh" setup (in a typical range), the displaced-field model yields a complete escape time on the order of 20 microseconds. The constant-volume model on the other hand gives a characteristic escape time (i.e., the time it takes for the concentration to reach 1/e of its initial value) on the order of 80 microseconds. We thus have a reasonable "branching" of the estimated values.

The penetration of field into plasma during the injection process was discovered from an analysis of magnetic probe data. Such information is contained in a number of papers (references 8, 12, 16). The constancy of plasma lifetime observed in experiments (see figure 7) with variations in magnetic field intensity over wide limits also testifies in favor of the supposition that there is a strong intermingling of field and plasma under the given conditions. Let us likewise note that the extremely short lifetime observed by Scott and Wenzel (reference 3) in their experiment coincides with the small transverse dimensions of their trap.

Let us now consider the problems of the spatial distribution of plasma in the trap. Figure 8 represents a photograph of plasma obtained during the compression of a pulsed discharge by cusped fields (reference 9). The flattened shape of the plasma formation localized in the medial plane of the system stands out quite clearly in this photograph. This same conclusion can be drawn from an examination of the motion picture still included in

article 11. Quantitative data on plasma topography in a cusped-field trap according to the measurements of Coensgen and others (reference 12) are presented in figure 9. As is apparent from the graphs, the plasma is more and more constricted towards the axis as we move away from the central plane of the system. The curves of radial plasma density distribution in relative units were obtained by integrating signals from electrical probes of special design.

In accordance with the above suppositions, plasma leakage from the trap must take place largely through the annular magnetic fissure in the central plane of the system. An ideally complete picture of plasma escape could be obtained by measuring energy losses from the plasma into the walls of the chamber on time with the aid of instruments with sufficient time and space resolution. This ideal experiment has as yet not been carried out, but figure 10 does show the distribution of the number of charged particles reaching an electrical probe as it depends on the co-ordinate (according to the data of American scientists (reference 12), while figure 11 shows the distribution of heat currents on a thermal probe for two values of the magnetic field obtained at one of the installations of the Atomic Energy Institute imini I. V. Kurchatov. It is apparent that the results of thermal and electrical measurements are in excellent agreement, confirming the supposition that energy and particle losses take place along the central plane. Of course, the thermal measurements are of an integral character; on the other hand, control measurements with electrical probes placed on the chamber walls confirmed the legitimacy of using thermal probes as sensitive to characterize plasma escape from the central region.

The dependence of magnetic fissure width on field intensity is represented in figure 12. The problem of whether the experimental dependence reflects the effect of a single magnetic field or whether it is effected by other factors as well remains undecided.

We pass on now to the results of density determinations. The values of plasma density in the central region of the trap depend on magnetic field intensity, injection conditions, and trap geometry. Table 2 contains a comparison of figures obtained for several cases. For the sake of convenience we have also included numerical data for plasma lifetimes in the same Table.

The values for plasma density included in Table 2 are typical in the sense that they correspond to working values for the magnetic field and injector operating re-

gimes. Plasma density in the trap increases with growing magnetic field intensity and voltage across the injector (reference 15).

Let us note that the values n cited in reference 8 are dubious since they were obtained with the aid of spectroscopic methods whose precise nature is described in but brief and vague terms by the authors.

Such are the basic results of studies on magnetic traps with cusped fields.

In discussing the prospects for future research we see that the efforts of the experimenters will be directed toward obtaining plasma of maximal initial density and temperature. On the one hand, this will require the perfection of injectors, and on the other the alteration of injection geometry and the geometry of the trap itself. How successful these efforts will be depends on whether traps of this type can compete with other systems and whether the solution will have to be sought in terms of some sort of hybrid system; the answer to these questions still lies in the future.

The authors wish to express their gratitude to L. A. Artsimovich, I. I. Gurevich, S. M. Osovets, and O. B. Firsov, with whom they discussed a number of the problems touched on in the present article.

Received 18 July, 1961

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Figures

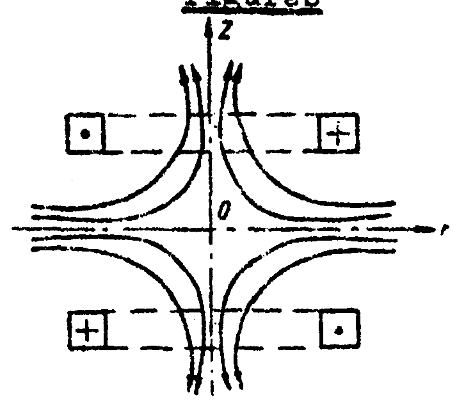

Figure 1. Lines of force of magnetic field in trap.

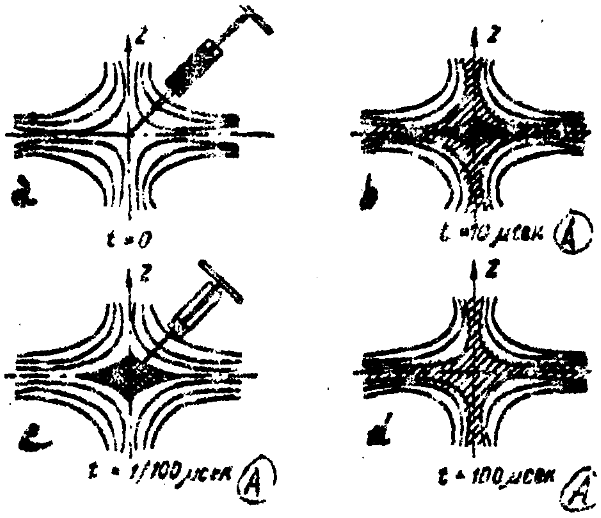

Figure 2. "Fast" injection of plasma into trap center.
A = Microseconds.

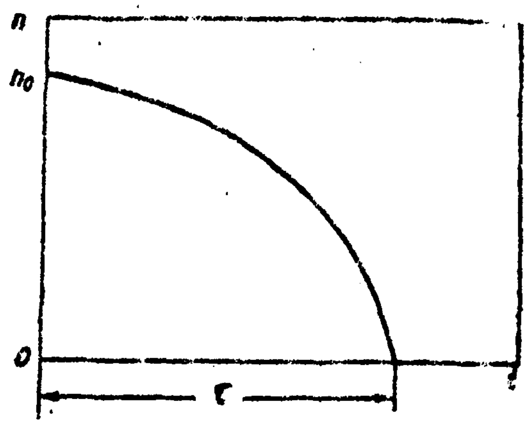

Figure 3. Dependence of plasma density on time. Displaced-field model.

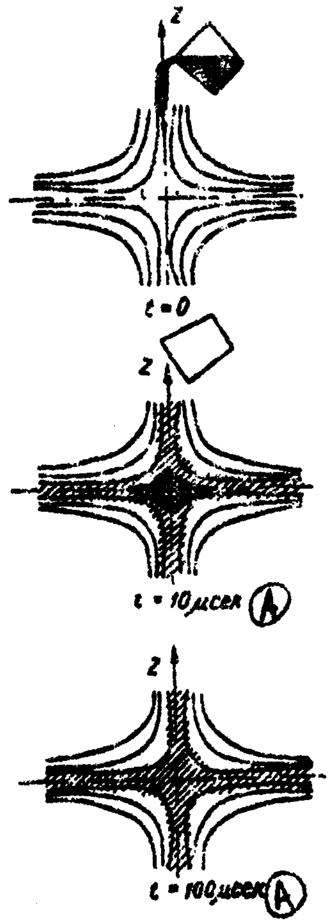

Figure 4. "Slow" injection of plasma into trap through axial magnetic fissure.
A = microseconds.

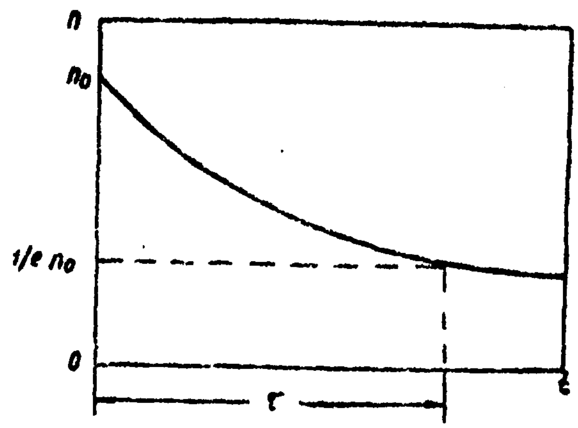

Figure 5. Dependence of plasma density on time. Model of plasma mixed with field.

Table 1

Type of setup, wall material	Diameter (max.), mm.	Diameter, mm.	Magnetic field, kilogauss	References
Cylindrical with orthogonal insert; metal............	200	1000	1.5	[7]
Cylindrical; glass	76	600	3.2	[8]
Cylindrical, with widened central portion; glass....	200	400	6.0	[11]
Cylindrical: metal	500	1500	3.5	[12]
Axially-symmetric of complex shape; metal ("Orekh" installation).....	900	1200	4.5	[16]
Cylindrical; quartz	180	350	25 (pulse)	[9]

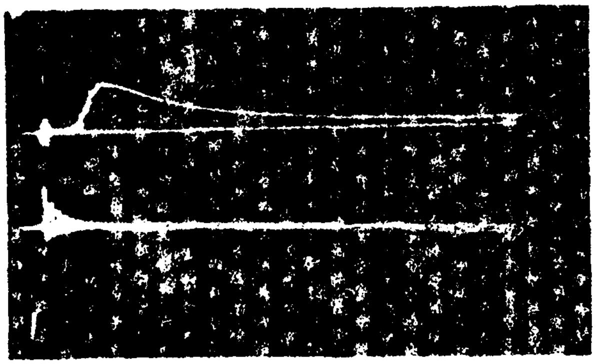

Figure 6. Ionic saturation current at probe (upper trace); Current in injector circuit (lower trace).

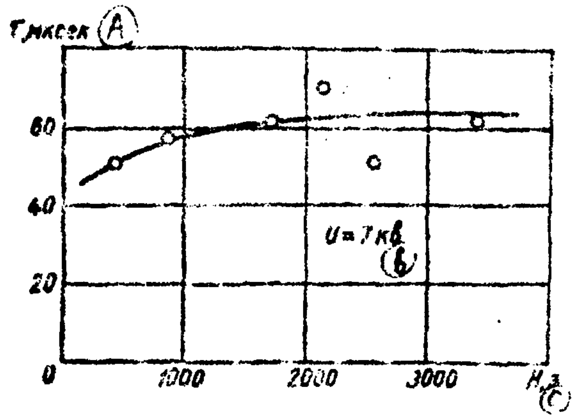

Figure 7. Dependence of plasma lifetime in trap on magnetic field intensity;
A = microseconds;
B = kilovolts;
C = oersteds.

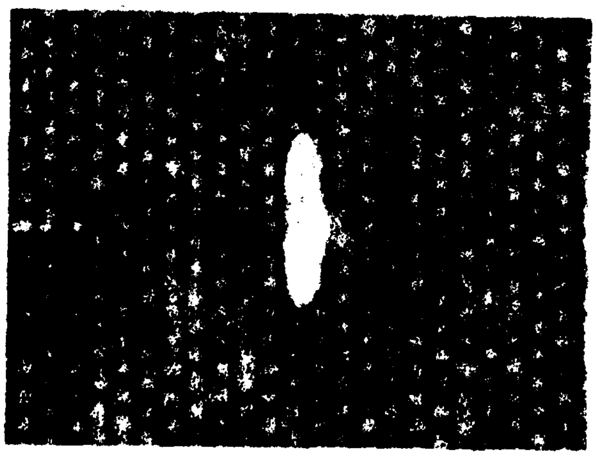

Figure 8. Plasma glow in trap: Pulsed field of 25,000 oersteds; initial deuterium pressure -- 0.5 mm of Hg; diameter of quartz tube exceeds the apparent glow diameter by about a factor of two.

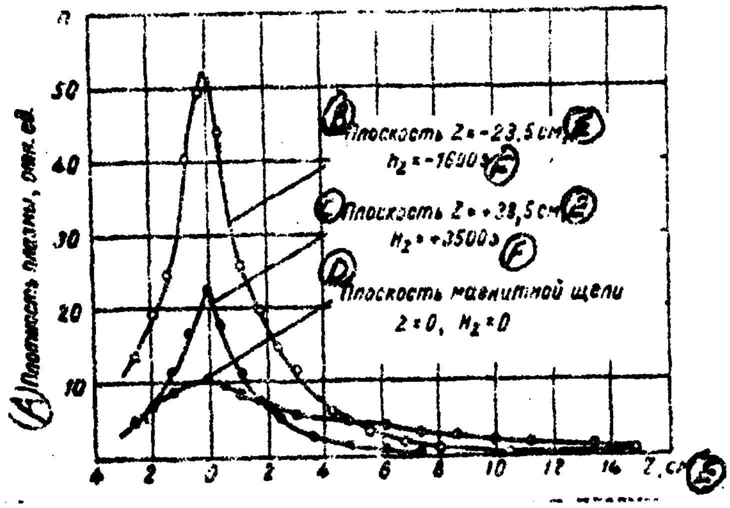

Figure 9. Radial distribution of plasma densities in various trap luminosities.
A = Plasma density, relative units;
B = Plane;
C = Plane;
D = Plane of magnetic circuit;
E = Centimeters;
F = Oersteds.

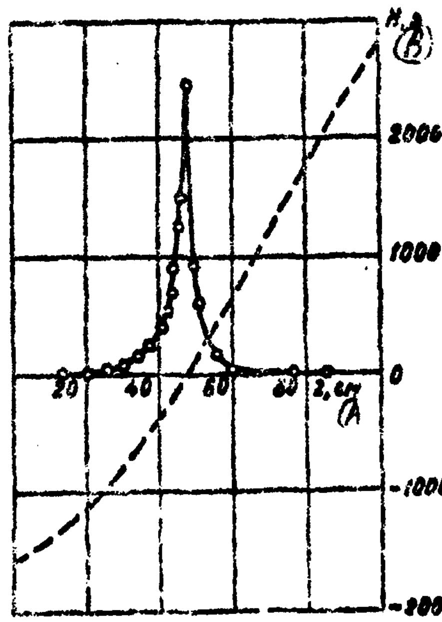

Figure 10. Flow to side wall of trap in region of magnetic fissure. Dotted line indicates course of H_Z component along axis.
A = centimeters; B = oersteds.

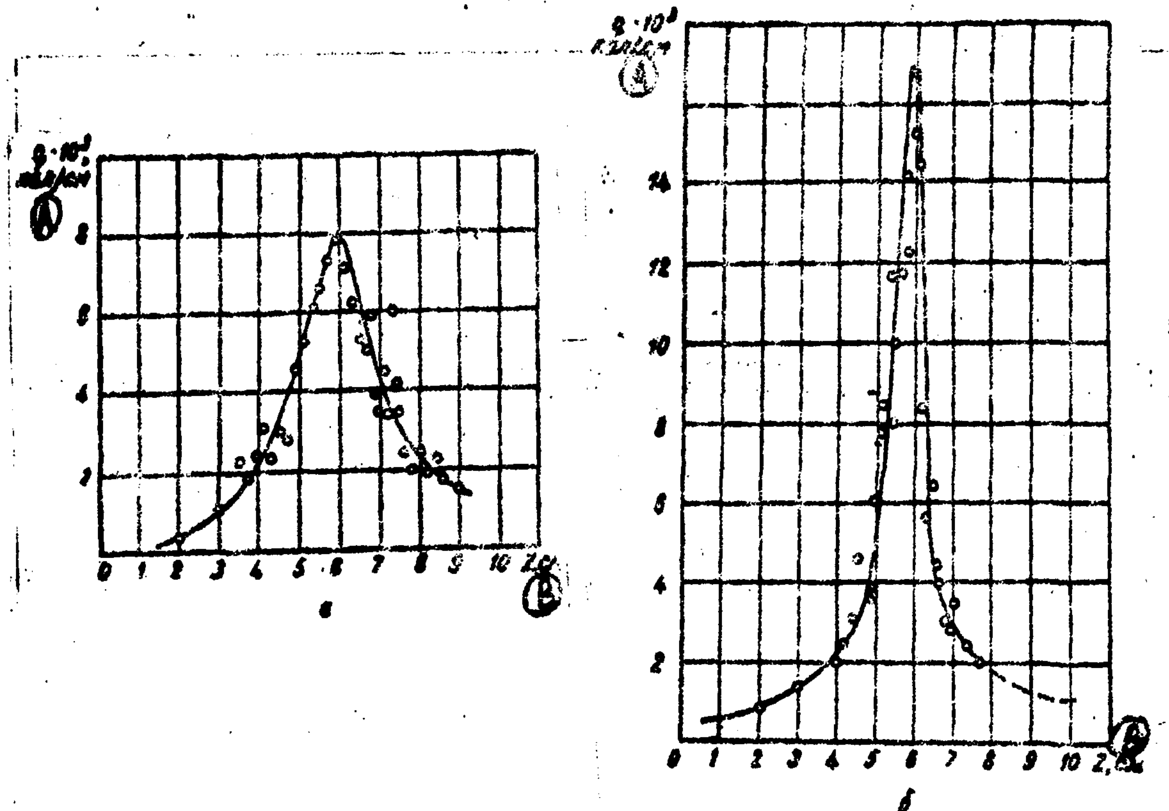

Figure 11. Emission of heat onto side wall of trap in region of magnetic fissure (a -- at H = 285 oersteds; b -- at H = 1000 oersteds).
A = calories/centimeter;
B = centimeters.

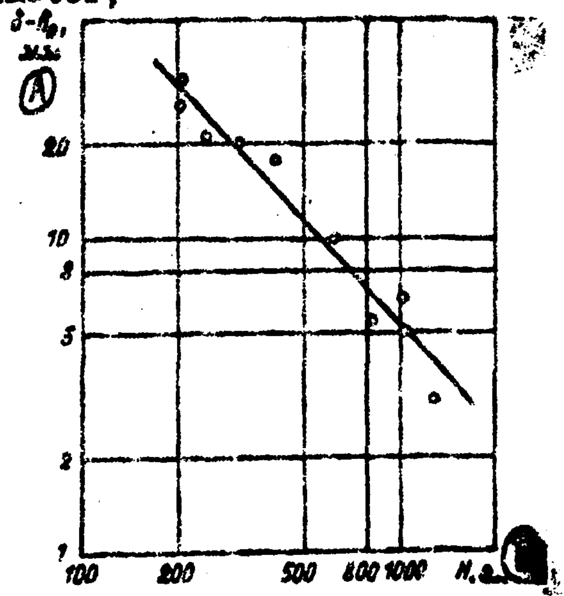

Figure 12. Dependence of width of magnetic fissure on field intensity.
A = millimeters;
B = oersteds.

Table 2

Plasma Densities and Lifetimes in Various Experimental Setups

Density n, cm^{-3}	Lifetime τ, microseconds	References
$3 \cdot 10^{12}$	40	[7]
$10^{11}-10^{12}$	100	[12]
$8 \cdot 10^{15}$	15	[8]
--	30	[13]
$10^{-13}-10^{14}$	60	[16]

THE FUTURE OF FAST REACTORS

/The following is a translation of an article by A. I. Leypunskiy, O. D. Kazachkovskiy, and M. S. Pinkhasik in Atomnaya Energiya (Atomic Energy), volume 11, # 4, October 1961, pps. 370-378./

The possibility of making exhaustive use of uranium for the needs of nuclear power production is connected with the realization of cycles of expanded nuclear fuel reproduction. It is a well known fact that this cannot be achieved with the aid of thermal or intermediate reactors. The reproduction coefficient in such systems for a closed uranium-plutonium cycle turns out to be less than one, and the uranium utilized in the optimum case can reach only several percent of the total quantity of extracted uranium. Thus, the industrial development of nuclear power production based on the utilization of thermal or intermediate reactors would lead to the rapid exhaustion of natural uranium resources and could not significantly expand existing power reserves. A different state of affairs prevails in the case of fast reactors These can be used to attain high values for the reproduction coefficient, considerably in excess of unity (~1.4 - 1.8).

The use of fast reactors will make it possible to solve the problem of exhaustive utilization of all uranium extracted, thereby satisfying the needs of man for energy for a very long time indeed.

The theoretical possibility of obtaining high reproduction coefficients in fast reactors was proved several years ago (references 1, 2). After this, the basic attention of scientists was directed toward the solution of engineering problems whose purpose was to investigate the problems involved in the technical realization of industrial fast reactors for power-producing purposes.

The characteristics of chain reactions based on fast neutrons differ considerably from those of fission chain reactions involving thermal neutrons. Inasmuch as the corresponding fission cross-sections are very small (approximately 200-300 times smaller than those for thermal neutrons) the concentration of fissionable material composing the critical mass in the active zone of a fast reactor must be much greater than in thermal systems. For the sake of comparison, in Table 1 we have listed nuclear fuel concentrations for several power-producing reactors (reference 3).

The second peculiarity has to do with the fact that in order to raise the reproduction coefficient in the active zone of fast reactors, it is expedient to make use of U-238 as the nuclear fuel solvent due to its relatively high fast neutron absorption effectiveness. Precise values for this absorptive efficiency depend on the neutron spectrum, but on the average it might be considered that the ratio of the radiation capture cross-section in U-238 to the plutonium (or U-235) fission cross-section for fast neutrons is approximately 20-30 times greater than in the case of thermal neutrons. This gives rise to the necessity for using either a fuel mixture consisting of Pu + U-238 with a high plutonium content, or highly-enriched uranium. Comparative data on uranium enrichment values in various reactors are listed in Table 1 (reference 3).

In themselves, the aforementioned difficulties do not occasion any special technical difficulties provided we speak of the creation of fast-neutron systems in general (for example reactors for physical or engineering research purposes). When we think of designing industrial power-production reactors, however, which first and foremost involve problems having to do with sufficiently high economic effectiveness, the peculiarities of fast-neutron

chain reaction give rise to certain rather complex technical problems. First of all, it is quite apparent that due to the high concentration of nuclear fuel required to reduce the relative role of capital investments having to do with the critical mass, we shall be obliged to intensify heat removal and to increase the energy intensity in the active zone. This of necessity requires the use of liquid-metal coolants, since gasses, for example, cannot assure the required degree of heat transfer, while water or organic fluids are useless by virtue of their retarding properties. The creation of a technology for the use of liquid-metals as heat transfer agents on an industrial scale is one of the more important problems to arise in the development of fast reactors. Apparently the greatest promise lies in the use of a sodium heat transfer agent. Comparative thermo-technical data for several power-production reactors are listed in Table 1.

The last line of Table 1 contains values for the basic quantity which characterizes the economic benefit of capital investments for nuclear fuel (specific power). As is obvious from the Table, thermal reactors can attain the same high values for specific power as thermal reactors. Design possibilities, generally speaking, make it possible to obtain even higher specific power values. But from the economic point of view this is already inadvisable; further increases in specific power result in increasing amounts of fuel left after removal from the reactor (prior to chemical reprocessing) to allow for the lessening of activity; this in turn has an adverse effect on the economic indices of the cycle. The quantity of residual fuel increases with growing specific power in the active zone. Actually, the greater the energy intensity in a reactor of a given power, the smaller its size and the greater the necessary fuel enrichment (due to increased neutron leakage). As a result of a given maximum depth of fuel mixture burnout, the amount of fuel extracted per unit time increases. The effect of this increase for high energy intensities predominates over the effect of decreasing critical mass. Typical curves of the dependence of the quantity of nuclear fuel employed in the fuel cycle in the case of a fast reactor for an atomic electrical power station presently being designed on the energy intensity for a given power rating of 750 megawatts are shown in Figure 1.

Curve M shows the presence of an optimum point lying in the region of relatively large heat production values. It should be noted that the magnitude of energy intensity likewise effects operating costs, since the quantity of

nuclear fuel processes varies with changing enrichment levels (per unit of energy produced), correspondingly altering expenses for chemical reprocessing. This effect depends on the cost of chemical reprocessing and leads to a certain decrease in the value of the economic optimum point.

Another technical problem has to do with greater fuel concentration in the fuel mixture (greater enrichment). In order to decrease expenses and losses in the chemical reprocessing of irradiated fuel, it is necessary to increase the degree of fuel mixture burnout. For purposes of illustration, Table 2 indicates the dependence on the quantity of reprocessed fuel on the degree of fuel mixture burnout for a mixture containing 21.6% of a nuclear fuel, and the corresponding decrease in the reproduction coefficient. The magnitude of losses for each reprocessing cycle is taken to be 2%.

In the general case for equal degrees of fuel mixture burnout, expenses for chemical fuel reprocessing for fast reactors must be greater than for thermal reactors due to a high degree of enrichment. At the same time, fast reactors have a greater potential for attaining a higher degree of burnout. The fact of the matter is that the time of operation of heat-producing elements in fast reactors is determined not by the reactivity losses (as is usually the case in thermal reactors), but by the mechanical stability of these elements in the radiation field. The creation of heat-producing elements designed for deep burnout represents yet another important task in the development of economical power-producing fast reactors.

In order to solve the basic technical problem standing in the way of the industrial development of fast reactors, the Soviet Union has built the BR-5 engineering research reactor (references 1, 4). This sodium-cooled reactor was designed for a maximum heat-producing capability of 5000 kilowatts. Its fast neutron stream has an intensity of 10^{15} neutrons/cm^2 · second. The reactor is designed to solve a number of problems, the most important of which are listed below.

1. The complex testing of cooling systems and the accumulation of working experience with radioactive sodium coolants.
2. The testing of individual samples and prototypes of heat-producing elements for industrial reactors to attain the greatest possible degree of fuel burnout under conditions close to those encountered in industry.
3. The study of fast reactor kinetics under conditions

of high energy intensities.

4. The performance of experiments in nuclear physics and studies of materials under conditions of intense fast neutron streams.

From its very inception, the BR-5 installation was intended to be used in the testing of power equipment which, obviously, would be quite remote from that required in actual industrial installations with regard to both size and power. The use of a turbine would only complicate the operation without yielding any useful results; for this reason, the reactor operates without producing electrical energy and the heat produced is released into a stream of water and the surrounding air.

The nuclear fuel used in the reactor consists of plutonium oxide, whose use in place of metallic plutonium was dictated by its high melting point, good compatibility with surrounding structural materials, and as was determined by preliminary experiments, its stability in the radiation field. The plutonium oxide is enclosed in stainless steel tubes arranged in heat-producing aggregates. Blueprints of such an aggregate and heat-producing elements are shown in Figure 2. The active zone consists of 80 such aggregates. In addition to this, it also includes aggregates with natural uranium, as well as special containers with various samples to be irradiated by neutrons. As is known, the reactivity of a reactor with a high K_∞ (such as the BR-5 reactor) can be significantly affected even by relatively small changes in the active zone geometry (within the limits of technical tolerances and temperature expansion). It is important to bear in mind at this point that the presence of a heat-production gradient along the reactor radius can in principle give rise to undesirable positive components in the power reactivity coefficient. For this reason the design for the active zone, and especially of the system of plutonium tube reinforcement in the heat-producing aggregates and aggregates within the lattice incorporated necessary features to improve the stability of the system. The active zone has the approximate form of a cylinder with a diameter and height of about 280 millimeters placed within a thick-walled central tube made of stainless steel. The stream of sodium coolant passes through the tube.

Since the reactor is not intended for practical reproduction of nuclear fuel, the use of uranium (either natural or impoverished) in the reflector is not mandatory. The use of uranium at this point, moreover, would lead to increases in the intensive heat-production region and the appearance of certain technical difficulties with

regard to reflector cooling. For this reason, the reflector was made of nickel which has a high albedo for fast neutrons and good heat conducting properties. Maximum heat-production in the reflector equals 220 kilowatts. The removal of this heat is realized by means of pumped air.

The regulation of this reactor is based on the principle of varying the system reactivity by shifting the internal nickel reflector layers. To reduce reactivity, the movable portion of the reflector is lowered. When the reactor must be shut off quickly, the circuit which feeds special retainer-electromagnets is broken and the internal reflector is lowered by the force of its own weight. A longitudinal cross-section of the reactor is shown in Figure 3 (see attached plate).

The system for removing heat from the active zone is composed of several circuits and 2 loops (figure 4). It was designed with due regard for the necessity of obtaining the most varied possible practical experience with liquid metal coolants. The sodium in the first coolant circuit, upon emerging from the central pipe, branches off into 2 similar streams flowing along identical loops. Each loop includes a heat exchanger for conveying heat into the second circuit and a circulation pump. The first circuit is supplied with plug valves which make it possible to remove the heat from each of the loops separately. The maximum flow rate of sodium in the active zone is 5 meters/second, and its temperature upon emergence from the active zone is $\sim$500 degrees C. The coolant in the second circuit consists of a eutectic alloy of sodium and calcium with a melting point of minus 12 degrees C. Both circuits are supplied with cold traps for oxide removal. The rate of coolant consumption in each circuit equals 250 cubic meters/hour. The total amount of liquid metal in the system is $\sim$ 5 cubic meters.

Heat is removed from the loops in the second circuit by 2 methods. One of the loops has an air heat exchanger in which the heat is removed by a stream of atmospheric air pumped in by a ventilator. The other loop contains a steam generator. The resulting steam is used either for technical purposes or is condensed in a continuous-flow refrigerator. The cooling system likewise incorporates features which make it possible to remove heat whenever it is necessary to stop the reactor. Residual heat may be removed from the active zone and transferred to the air with the aid of natural convection even with all electricity to the reactor shut off.

Physical test runs on the reactor without any coolant

were carried out in the summer of 1958. January 1959 marked the attainment of the critical state in the sodium-filled system. After this, a period of adjustment and improvement of individual circuits continued for several months, so that by the summer of 1959 it was possible to initiate work with the reactor according to original design parameters; this work is presently continuing. The installation turned out to be extremely stable and convenient in exploitation. We should note the reliable operation of the equipment which in most cases was not of the standard type and had to be specially produced for the given system. The reactor operated in various regimes in accordance with experimental needs. Maximum power output (5000 kilowatts) or output values quite close to this figure was maintained throughout a large portion of the operating time. The total operating time of the reactor at this power level amounted to over 80% of the time last year.

The operation of the reactor has yielded important results contributing toward the solution of the problems posed. We have now to a considerable extent mastered the techniques of working with a radioactive sodium coolant. It turns out that sodium by virtue of its operating properties is a perfectly acceptable heat transfer agent. For example, it is in many respects superior to water since it creates no difficulties having to do with corrosive effects, nor does it require high pressures. The convenience of using sodium also makes itself felt in replacing equipment in the cooling system. Such replacements can be safely carried out without draining the circuit simply by freezing the sodium in the required sections of piping. In this respect, sodium likewise is superior to the Na-K alloy. The use of cold traps assures the lowering of oxide concentration in the coolant down to the required value of $\sim 1-3 \cdot 10^{-3}$ %.

Work with the reactor has demonstrated that the heat-producing element design employed is quite reliable. Suffice it to say that by June 1961, the reactor attained a maximum degree of fuel burnup in excess of 4%. The magnitude of the integral fast-neutron stream which irradiated the heat-producing elements exceeded $2 \cdot 10^{22}$ neutrons/square centimeter. Moreover, this was not accompanied by any signs of the presence of plutonium in the sodium, confirming the sufficient mechanical strength of the heat-producing elements. The resulting operating data confirmed the expediency of using a ceramic nuclear fuel. At burnout levels on the order of those attained, the relative quantity of processed nuclear fuel for fast

reactors is comprable with the corresponding quantity employed in thermal reactors. At the same time, the total volume of chemically reprocessed fuel is decreased considerably (by lowering the quantity of U-238 to be reprocessed. Apparently for this reason, the use of a ceramic fuel is more profitable as compared to a metallic fuel, despite some lowering of the reproduction coefficient (due to retardation by oxygen nuclei) and increased enrichment (due to lower uranium nuclear density).

Tests were carried out on the stability of reactor operation, which confirmed the results of preliminary calculations. The static power coefficient of reactivity was measured experimentally and turned out to be negative with a magnitude on the order of $10^{-5}\cdot C^{-1}$ (with respect to sodium temperature at the outlet). Studies in transition regimes showed the absence of positive components with very short periods in the dynamic power coefficient of reactivity of the reactor. The temperature coefficient of reactivity with respect to the sodium temperature at the intake also turned out to be negative ($2\cdot 10^{-5}\cdot C^{-1}$). As is known, the temperature coefficient of reactivity by itself does not have a very significant effect on the stability of reactor operation, inasmuch as this coefficient involves a rather large lag corresponding to the period of the coolant circulation cycle. In the case of the BR-5 reactor, this period equals approximately 30 seconds.

Throughout the entire time of reactor operation, there was not a single instance of anyone receiving an overdose of radiation despite the fact that maintenance work had to be performed both in the active zone and in the primary contour containing radioactive sodium. There are no signs of radioactive contamination in any portion of the area which houses the reactor, which is fully accessible to personnel.

Following over two years of work with the BR-5 reactor and the achievement of positive results in the solution of basic technological problems involved in the creation of power-producing fast reactors, ever greater importance is assumed by the economic problems of such systems. It is quite obvious that in order to compile a concrete program for the industrial construction of fast reactors it is necessary to have data about their economic effectiveness. We have to be able to compare the economic indices of atomic electrical power stations employing fast reactors with those of other atomic stations, as well as electrical power stations of the standard type. Such comparisons must be carried out both for the near future

and for more extended periods, taking into account increased needs for power, changes in available fuel resources, and the emergence of various new ways for improving the technical-economic indices of atomic electrical power stations.

Unfortunately, the determination of the economic indices for the functioning of future industrial atomic electrical power stations with sufficient accuracy is as yet an extremely difficult task. First of all, the methods of determining these indices have not as yet received sufficient elaboration. For example, we are not as yet completely clear on such points as how to properly calculate the costs of nuclear fuel employed in the fuel cycle, the price of the secondary nuclear fuel, etc. These questions will apparently be investigated through the joint efforts of economists and specialists in the field of nuclear power production. The greatest difficulty, however, is the lack of necessary experience which would make it possible to determine the cost of constructing and operating typical industrial atomic electrical power stations. The only way to overcome this difficulty is to create experimental industrial installations of various types. As is known, it is precisely this principle that lies at the basis of the Soviet program on nuclear power production today. A plan for the development of industrial fast reactors of varying output and design has already been worked out in accordance with this program.

The economics of atomic electrical power stations with such reactors depends considerably on the power output of the entire station. This dependence is dictated not only by the usual effects of size on relative capital investments and operating costs, but likewise by certain additional factors stemming from peculiarities and physical properties of fast reactors. As is known, as the size of any reactor increases, the relative quantity of neutrons escaping from the active zone decreases, and consequently, the extent of necessary fuel enrichment in the active zone likewise drops off. In the case of industrial power-producing thermal reactors, however, the effect of neutron leakage is small and can be neglected in practice. On the other hand, in the case of fast reactors, even of the largest size, the effect of neutron leakage and its variation with differences in reactor size turn out to be quite significant. For this reason, as the power output (or size) of a fast reactor increases, the concentration of nuclear fuel is reduced significantly. This results in a considerable improvement in such economically important characteristics as specific power (mak-

ing possible an additional reduction of capital investments) and extent of fuel burnout (lowering chemical reprocessing costs). Rough values of fast reactor indices employing a ceramic nuclear fuel will be found in Table 3 below.

It should be noted that an even greater decrease in nuclear fuel concentration within the active zone can be attained by using inert solvents in place of U-238 (reference 5). Some reliance on the use of inert solvents will only be possible, however, when we can successfully prove that this will not lead to inordinately large losses in the reproduction coefficient. As a whole, it might be said that the economic effectiveness of atomic electrical power stations with fast reactors will increase more rapidly as reactor power increases than will that of electrical power stations with thermal reactors and standard thermal stations.

The possibility of creating economically profitable atomic electrical power stations based on fast reactors is being successfully confirmed by the work of the BR-5 reactor. It is exceedingly important to note the fact that the BR-5 reactor was successful in attaining and reliably maintaining basic technological indices which are close to those of a typical power-producing reactor. For the sake of comparison, we have listed below some of the more important perameters of the BR-5 reactor and an atomic electrical power station with a fast reactor with a thermal power of 750 megawatts:

	BR-5	750-megawat reactor
Energy intensity, kilowatts/liter.......	360	600
Heat transfer agent temperature at reactor outlet, °C......................	500	550
Depth of fuel burnout,%..................	> 4	~ 5

Following the construction of a semi-industrial or industrial power-producing fast reactor and the accumulation of sufficient operating experience, we shall be able to determine the necessary economic data for the compilation of the concrete program for the future and the clarification of the place to be assumed by fast reactors in the total program of nuclear power production development. It is already possible, however, to cite a number of serious qualitative arguments in favor of fast reactors. These arguments render quite plain the important role and

economic promise of such systems.

First of all, it is necessary to note that data concerning the depletion of standard power resources and growing power needs for the future leave no doubt as to the role of nuclear power production in the industries of the future. Primary reliance will be placed on nuclear fission techniques, inasmuch as studies in the field of power production by nuclear fusion have not emerged from the stage of laboratory experimentation (thus rendering any predictions along this line premature).

Of all the reactors being developed at the present time, fast reactors have the advantage of a large reproduction coefficient. This advantage is decisive if the fuel we intend to employ is uranium. The question of the best type of reactor using thorium is as yet unsolved, even though here too fast reactors have definite advantages. And so, fast reactors are the only type of system which permit the exhaustive utilization of available uranium for power-producing needs. For this reason, the expediency of designing such reactors is beyond dispute.

The economic advantage of fast reactors is based on a number of factors. First of all, their large reproduction coefficient tends to effect a considerable lowering of the fuel component in total power producing costs. On the other hand, it is of course necessary in calculating the fuel component to take into account expenses incurred throughout the fuel cycle. A considerable portion of the fuel component may consist of expenses for the chemical reprocessing of fuel material from the active zone and reflector.

The chemical reprocessing of an irradiated fuel removed from a fast reactor can be carried out by standard hydrochemical techniques. The best possibilities in this case emerge, however, when we consider the use of new and more advanced methods of chemical reprocessing not involving the use of water and water solutions: pyrochemistry, electrochemistry, etc. These methods are particularly advantageous when applied to fast reactor fuels, since, in the first place, the relatively small amounts of material to be reprocessed afford a greater possibility for designing simple and compact technical installations and secondly, because there is a considerable increase in the permissable quantities of simultaneously reprocessed material (due to the absence of a hydrogen retarding agent)

It is noteworthy that the application of such methods as pyrochemistry and electrochemistry will make it possible to curtail considerably the time taken up by the cooling of the fuel and the dropoff in its activity. This will lead

to a sharp reduction in the total amount of fuel employed in the cycle and a concomitant reduction in costs. Approximate data on the relative quantity of fuel employed in the fuel cycle of an atomic electrical power station with a fast reactor (for various reprocessing methods) are given below

	Hydrochemistry	Pyro-(electro-) chemistry
Quantity of fuel in reactor,%.....	100	100
Quantity of fuel retained prior to chemical reprocessing,%...........	100	20
Total quantity of fuel in cycle,%..	100	55

The cost of preparing heat-producing elements likewise enters into the fuel component. In the case of fast reactors, due to the possibility they afford of attaining deep fuel burnout as determined by the fast-neutron chain reaction, the quantity of heat-producing elements necessary is not great with relation to the energy produced. Consequently, the manufacturing cost in the fuel component will likewise be rather small. In addition to this, fast reactors require less uranium. The rate of new nuclear fuel accumulation in an atomic electrical power station with a fast reactor, particularly when new methods of chemical reprocessing are employed, turns out to be extremely high, reaching values on the order of 12-15% per year. Consequently, the fuel needs of fast reactors will depend largely on the initial quantity of U-235 or Pu-239 provided. Waste uranium can be employed as the nuclear raw material employed in the reflector as well as in the active zone.

The entire concrete program, scale, and schedule for the construction of fast power-producing reactors, as well as their economic indices for the near future will be determined after work has been completed on a number of experimental installations. Even today, however, we can speak of the promise such systems hold for us.

Received 17 July, 1961

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Table 1

A Сравнительные характеристики реакторов различных типов

B Характеристика реактора	C Атомные электростанции с тепловыми реакторами					D Атомные электростанции с быстрыми реакторами	
	E Белоярская (СССР)	F Ново-Воронежская (СССР)	G «Янки атомик» (США)	H Дрезденская (США)	I Брадуэлская (Англия)	J «Энрико Ферми» (США)	K Проектируемая (СССР)
L Тепловая мощность, *Мвт*	285	710	392	626	531	300	750
M Горючее	U^{235}	U^{235}	U^{235}	U^{235}	U^{235}	U^{235}	U^{235}
N Концентрация горючего в активной зоне, г/л	5	34	94	38	2	1360	625
O Обогащение, %	1,3	1,5	3,4	1,5	T Природное	25,6	21,6
P Теплоноситель	S Вода	S Вода	S Вода	S Вода	CO_2	U Натрий	U Натрий
Q Энергонапряженность, *квт/л*	1,2	43	52	29	0,6	855	600
R Удельная мощность, *квт/кг*	250	1200	550	670	320	620	950

A = Comparative characteristics of various types of reactors;
B = Reactor description;
C = Atomic electrical power stations with thermal reactors;
D = Atomic electrical power stations with fast reactors;
E = Beloyarsk (USSR); F = Novo-Voronezh (USSR); G = "Yankee Atomic" (US);
H = Dresden (US); I = Bradwell (England); J = "Enrico Fermi" (US); K = Planned (USSR);
L = Thermal power, megawatts;
M = Fuel;
N = Fuel concentration in active zone, grams/liter;
O = Enrichment, %;
P = Heat transfer agent;
Q = Energy intensity, kilowatts/liter;
R = Specific power, kilowatts/kilogram;
S = Water;
T = Natural;
U = Sodium.

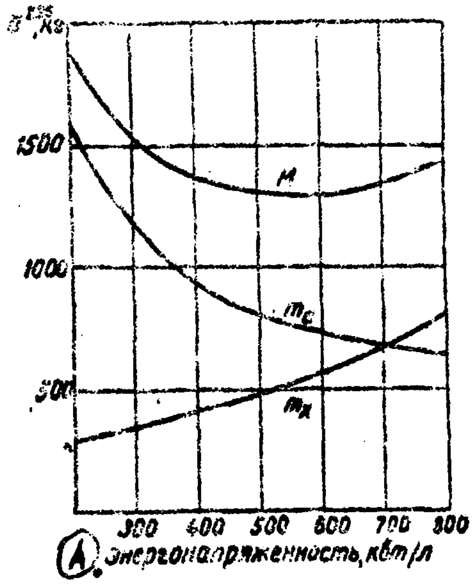

Figure 1. Dependence of the amount of fuel in a cycle on the energy intensity in the active zone of a fast reactor: M -- total amount of fuel; m_x -- amount of fuel in reactor; m_a -- amount of fuel outside reactor.
A = Energy intensity, kilowatts/liter.

Table 2

A = Reprocessing and reproduction of fuels for fast reactors;
B = Depth of fuel misture burnout, %;
C = Quantity of reprocessed fuel per 10^6 kilowatt-hours of electrical power, kilograms;
D = Reduction of reproduction coefficient.

(A) Переработка и воспроизводство горючего для быстрых реакторов

(B) Глубина выгорания топливной смеси, %	(C) Количество перерабатываемого горючего на 10^6 квт.ч электроэнергии, кг	(D) Уменьшение коэффициента воспроизводства
1	0,835	0,43
2	0,418	0,21
5	0,187	0,08
20	0,0418	0,02

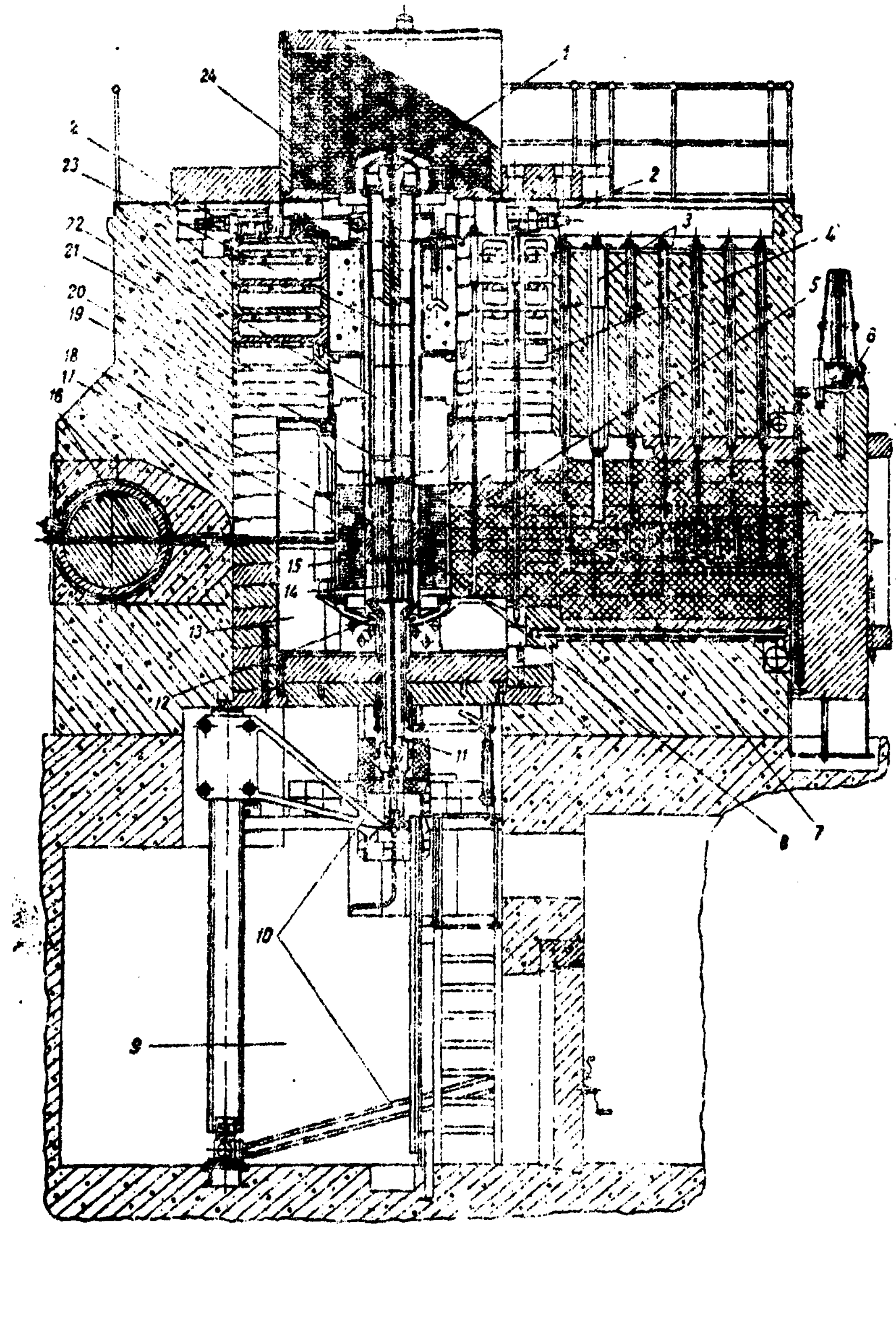

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Figure 3. [Blueprint] Longitudinal cross-section of BR-5 reactor.

1 -- Reloading mechanism;
2 -- Control and shielding system motors;
3 -- Vertical experimental channels;
4 -- Concrete shielding;
5 -- Compensating cylinder;
6 -- Thermal column gate valve;
7 -- Thermal column;
8 -- Movable screen;
9 -- Lower reactor box;
10 -- Devices for remote reloading of samples in loop channel;
11 -- Heat transfer agent supply main;
12 -- Reactor jacket;
13 -- Water shielding tank;
14 -- Central loop channel;
15 -- Automatic regulation system control shaft;
16 -- Neutron beam channel gate valve;
17 -- Stationary nickel channel;
18 -- Active zone;
19 -- Cast iron shielding;
20 -- Main reactor tube;
21 -- Main concrete shielding;
22 -- Rotating plugs in heat-producing assembly reloading system;
23 -- Heat transfer agent in main tube;
24 -- Protective plug.

Figure 4. Diagram of BR-5 installation:

1 -- Reactor;
2 -- Main circulatory pump;
3 -- Intermediate heat exchanger;
4 -- Second-level circulatory pump;
5 -- Air heat exchanger;
6 -- Steam generator;
7 -- First-contour cold oxide trap;
8 -- Oxide indicator;
9 -- Second-contour cold oxide trap;
10 -- Second-contour oxide indicator;
11 -- Filtration system recuperator;
12 -- Distaillation pump;
13 -- Tank for radioactive sodium;
14 -- Tank for Na-K alloy;
15 -- Central loop channel;
16 -- Circulation pumps of the loop-channel system;
17 -- Cold trap and oxide indicator of loop-channel system;
18 -- Dauthermal vaporizer;
19 -- Dauthermal vapor condenser;
20 -- Cooling system for regulatory operating mechanisms of system and shielding;
21 -- Water shieoding tank cooling system;
22 -- Preliminary reactor heating system.

Table 3

A = Dependence of fast-reactor characteristics on their thermal power;
B = Thermal power, megawatts;
C = Enrichment, %;
D = Specific power, kilowatts/kilogram;
E = Quantity of reprocessed nuclear fuel (U-235), kilograms/ 10^6 kilowatt-hours.

A

Тепловая мощность, Мвт B	Обогащение, % C	Удельная мощность, квт/кг D	Количество перерабатываемого ядерного горючего (U^{235}), кг/10^6 квт·ч E
200	32,5	485	0,27
4[illegible]	28,5	6[illegible]0	0,22
75[illegible]	21,6	[illegible]30	0,18
150[illegible]	18,5	[illegible]60	0,16
3000	17,2	1060	0,14

SOME RESULTS AND PERSPECTIVES OF ISOTOPE AND NUCLEAR RADIATION USE IN INDUSTRY AND RESEARCH IN THE USSR

/Following is the translation of an article by P. L. Gruzin in Atomnaya Energiya (Atomic Energy), volume 11, # 4, October 1961, pps. 379-394./

The achievements of nuclear physics are gaining ever wider use in the most diverse fields of science and technology. At the present time it is difficult to list even the most important results obtained through the use of these achievements. One final result of the work of Soviet scientists and engineers in this area has been the creation of a new branch of science--applied nuclear physics which is based on such studies as the use of stable and radioactive isotopes, nuclear radiations in industry and scientific research, the utilization of atomic reactors and accelerators of charged nuclear particles in research work as well as in the study of the effects of ionizing radiation on the properties of materials and technological processes. The present article describes only some of the results of using isotopes and nuclear radiations in scientific studies and industry.

The method of "marked atoms" based on the use of stable and radioactive isotopes has gained wide acceptance in physical, chemical, geological and other studies. This technique makes it possible for scientists to obtain certain important results faster and with greater accuracy than do other methods; in addition it is frequently used in cases where other techniques cannot be employed. With the aid of radioactive isotopes, it is possible to study the kinetics of many rapid processes, something which cannot be done by any other means.

The main distinguishing characteristic of methods based on the use of radioactive and stable isotopes as indicators is their high sensitivity and usefulness in the

investigation of extremely small quantities of material. Thus, for example, with the aid of radioactive isotopes it is possible to determine the percentage concentration of phospherous, cobalt, and other element admixtures with an accuracy of about 10^{-10} %.

Isotopic techniques likewise make it possible to study the character of admixture distribution in various materials, conditions operative in the attainment of a state of equilibrium among elements in various phases, the mobility of atoms in liquid and solid bodies, to maintain control over the state of individual links in metallurgical aggregates, to study the behavior of various materials in technological processes, etc.

Scientists and industrial workers must strive to determine the most effect trends for the further extension of the practical applications of nuclear physics. New methods and principles for studying, controlling, and intensifying technological processes based on the use of isotopes and nuclear radiation are being developed and employed, as a rule, with the most timely and complex scientific-technical problems in mind.

The wide us of nuclear physics methods in Soviet industry began in the 1940's. At the present time numerous enterprises and scientific research institutes have created dozens of radiometric laboratories concerned with fundamental studies, the elaboration of methodological problems, and research on the control and improvement of technological processes. Radioactive isotopes were first employed under industrial conditions at the Novaya Tula Metallurgical Plant and the Kuznetsk Metallurgical Combine. At the present time, isotopes are being used succesfully at such major Soviet enterprises as the Kuznetsk and Magnitogorsk Metallurgical Combine, the "Azovetal'", imini F. E. Dzerzhinskiy, Stalinskiy, Makeyevskiy, and imini Il'yich Metallurgical Plants, the "Yuzhuralnikel'" Combine, the Volkhov Aluminum Plant, the Krivoy Rog Yuzhnyy Ore Enrichment Combine (YuGOK), etc., etc.

At the present time, the following major trends in the use of isotopes and nuclear radiations have become prominent in science and industry:

1) Scientific and technological studies for the deeper investigation of the properties of materials, the discovery of the mechanisms involved in various physico-chemical processes, the analysis of admixture content in pure and extra-pure materials, the study of atomic displacement processes, the structure of matter, etc.;
2) Geophysical studies in petroleum, gas, coal, and

mineral ore prospecting and extraction;

3) Control, regulation, signalization, automation, and mechanization of technological processes;
4) The creation of new industrial processes (polymerization, sulfochlorination, oxidation, materials sterilization, electrostatic charge removal, etc.), initiated or intensified by radiation;
5) Defectoscopy without the destruction of manufactured articles.

Let us examine the basic results of certain studies carried out in this field.

1. Prospecting, Surveying, and Exploitation of Useful Ores

Methods and instruments based on the use of radioactive isotopes and nuclear radiation are employed in prospecting, surveying, and extracting petroleum, gas, coal, and minerals. Geological organizations under various sovnarkhozes (Councils of the National Economy) engaged in the surveying and exploitation of petroleum and gas deposits through the direct application of these methods have investigated millions of linear meters of both prospecting and exploitative bore holes.

In such instances, nuclear radiation and isotopes are employed for the study of geological bore cross-sections and control over their technical state, as well as the study and control of various processes connected with the development of petroleum and gas deposits. Recently, the method of radiometric surveying has come into its own in the search for petroleum and gas deposits.

The method of γ-carotage consisting in the measurement of γ-ray intensity of various minerals within the bore hole is employed, as a rule, to gain a more precise lithological picture of the region. An important advantage of this method, as of other radiometric techniques, over other geophysical methods is the possibility of carrying out measurements in bore holes reinforced by metallic tubing. This has made it possible in several areas to obtain new and important data on the geological structure of old bores completed prior to the advent of geophysical surveying methods, or to obtain the same data for bore holes lacking in geological documentation. γ-carotage diagrams are successfully employed in determining strata to be tested for petroleum and gas content. The result of such efforts in Azerbaydzhan and the Western Ukraine has been the renewed exploitation of hundreds of

abandoned bore wells which have since yielded several hundred thousand tons of oil.

The method of neutron γ-carotage based on the registering of the results of interactions between neutrons and atoms composing a given mineral statum, just as the method of γ-carotage, is usually employed in bores dug for the purpose of finding petroleum or gas. In combination with other geophysical methods (electrometry, γ-carotage and cavernogrammy), it affords a considerable improvement in the reliability of the interpretation of diagrams both in the demarcation of promising strata containing petroleum or gas, and in rendering more precise pictures of bore lithology. At the present time, about 50% of prospecting bores dug with the purpose of finding either petroleum or gas are investigated by the method of neutron γ-carotage.

The method of neutron-neutron carotage, when the dectector of a bore instrument registers the intensity of thermal or super-thermal neutrons retarded in the surrounding mineral strate holds out great promise for the quantitative determination of mineral porosity. In this case, the measured effects of super-thermal neutron redistribution as compared with the redistribution of thermal neutrons is considerably less dependent on the mineral content in the stratified water and bore fluid.

It should be noted that a combination of the methods of neutron-neutron carotage according to thermal neutrons and neutron γ-carotage makes it possible to reliably determine the petroleum-water boundary in deposits containing water with a mineral salt concentration of 150 grams/litre and over in the case of mineral varieties similar both with respect to porosity and lithological composition.

The method of γ-γ-carotage based on measuring the intensity of dispersed γ-radiation makes it possible to maintain surveillance over variations in strata density. For this reason, γ-γ-carotage is of great interest both in the study of bore lithology and in the interpretation of gravimetric survey data. This method has received the widest application in the investigation of coal deposits, revealing as it does not only the coal layers, but their thickness and structure as well. Studies by the method of γ-γ-carotage are being conducted in the Chelyabinsk and Pechora Coal Basins, the central and western portions of the Donbass, and the coal deposits of the Primor'ye and the Eastern Ural deposit. The method is also employed in the Kuznetsk, Karaganda, Podmoskovnyy, and Yuzhno-Yakutskiy Basins and other coal mining areas

in the Soviet Union.

Whereas in 1955 the method of γ-γ-carotage was used in surveying only several hundred meters of prospecting bores, in 1959 the scale of this work exceeded 1,600,000 linear bore meters.

Radioactive isotopes (usually Zn-65, Fe-59, and Zr-59) have gained wide acceptance in the petroleum extraction industry for controlling the technical state of well bores and the solution of certain problems in industrial geology having to do with well sinking and exploitation.

Isotopes are used in determining reinforcement column breakdown points, water entry points in reinforced bores, fluid circulation zones exterior to the casing, the height of cement rise following cementation, the thickness of the cement casing; they are also used to obtain more precise measurements of column perforation depth, to carry out selective perforation of 2- and 3-layer columns, to define the perforated levels in uncased bores, and to establish the location of intensive absorption of the solution in the process of oil well sinking.

In a number of petroleum-bearing regions, the method of γ-γ-carotage is successfully employed to determine cement rise, casing eccentricity, the quality of cement distribution beyond the casing, and the depth of the casing pipe shoe in multi-column bore designs. The Volzhsko-Ural'skiy Affiliate of the All-Union Geophysical Methods Scientific Research Institute has developed, tested and successfully introduced a special instrument for this purpose--the VUF-1 cementometer.

Radiometric methods are also beginning to find use in the study of geological bore cross-section in the field of boron, lead, iron, bauxite, copper, and berylium prospecting, as well as in the solution of a number of problems in mineral geophysics.

Since 1958, some experimental-methodological work has been done on the photoneutron carotage method in berylium ore prospecting; this technique is based on the (γ, n) reaction. The technique makes it possible for mining engineers to locate all strata containing berylium of near-industrial quality. In the case of previously-surveyed deposits, the photoneutron method is an effective means of revision and re-evaluation. It can also be used in prospecting for berylium ores.

Also tested under bore conditions was the method of induced activity for the location and quantitative evaluation of copper, aluminum, silicon, cobalt, and manganese content in mineral ores. The identification of the aforementioned elements with the aid of other carotage

techniques does not always yield unambiguous results. A quantitative evaluation is possible in principle only by the method of activation analysis.

Activation techniques are also employed in the analysis of mineral ore (core) samples. Their advantage lies in the possibility of quickly determining the content of certain elements in ore samples (for example, indium, manganese, aluminum, silicon, vanadium, etc.) and the possibility of identifying extremely small quantities of a number of elements which cannot be detected by other means.

A method of selective γ-γ-carotage has been developed for copper, lead, and other heavy-element prospecting; in this technique, the qualitative and quantitative composition of the elements in which we are interested is determined by the intensity and spectral makeup of the dispersed γ-radiation.

Experimental work in mineral bores shows that radiometric carotage techniques are more effective than other geophysical methods of bore study. One of the more important tasks of future research in this area is that of improving radiometric methods and extending their potential in the study of mineral bores.

The basic purpose of efforts now underway in the mining and prospecting fields with regard to isotope applications is the expansion of the raw materials base and the introduction of new raw materials and fuels into industry, as well as their increased extraction under safer and more healthful conditions. In the coal and mineral ore industries, radioactive isotopes may be used chiefly in instruments of control and automation. Studies and the results of experimental tests in the application of radioactive isotopes and nuclear radiation in the coal and mineral industries have shown the usefulness of both these tools in effecting automatic control over coal levels in bunkers, the determination of proper times for driving in trough and spout openings, realizing the proper loading of charging skips, controlling the presence of coal or ore on a conveyor belt, sorting out pieces of waste material from chunks of coal, counting coal wagons, determining the percentage content of ash in coal, suspension densities, and pulp, studying the movement of various gases and fluid streams, determining their volume and the gas and water permeability of surrounding mineral varieties.

Work on the creation of γ-electron relays in the Soviet Union was begun in the 1950's. Test prototypes of such relays were tested at the Kemerovo, Sverdlovsk, and Chelyabinsk sovnarkhozes. The "KIP" Factory of the Khar'kov Sovnarkhoz organized the production of instruments

of this type for use specifically in the mining industry; they were called the "GR's" (gamma relays). One of the first major industrial enterprises to introduce automation based on the wide use of γ-electron relays was the Southern Ore Enrichment Combine of the Dnepropetrovsk Sovnarkhoz in the Ukrainian SSR, which has accumulated a considerable body of experience in employing instruments of the GR type. At that time the Combine was suffering definite losses having to do with the clogging of spouts with ore coming out of the rough fragmentation mill; this led to the tearing of transport belts and resulted in considerable ore losses. The ore dropping off the belts necessitated work stoppages and the use of additional man power.

In 1950, the reloading spouts in the rough fragmentation mill were provided with γ-electron relays of the GR-1 type (figure 1), which resulted in the complete elimination of the aforementioned shortcoming; similar equipment was subsequently installed in all of the reloading spouts of the medium and fine fragmentation mills (figure 2), thus assuring a considerable improvement in work rhythm and the complete elimination of conveyor belt cutting due to spout clogs.

At the same time, γ-electron relays are being used as switches in turning on the automatic ore watering systems at the instant when the ore is brought in on the conveyor belt. γ-relays are also used to regulate medium and fine fragmentation mill loading, completely preventing mill breakdown at this point.

Iron ores enriched at the YuGOK are characterized by a fine-grain structure. For this reason, the enrichment process is preceded by three fragmentation stages, and two pulverization processes designed to expose magnetite grains less than 0.1 millimeters in size.

The roller and ball mills at the enrichment plant are supplied with ore by a system of conveyors consisting of two parabolic bunkers of 40,000 ton capacity (each bunker consisting of 18 sections). The bunkers are loaded by two self-unloading driver-operated wagon dollies.

Following fine fragmentation, the ore is fed by conveyor into the upper portion of the enrichment system. Here the ore stream branches off onto two transporters with dollies which unload the ore into that section of the bunker over which the operator stops the machine. Quite naturally, the considerable depth of the bunker (10 meters) and the quantity of dust within it complicate the determination of the proper ore level and lead to disorderly bunker filling.

The effeciency of the ball mills and quality of the concentrate to a considerable extent depend on the standardization of the fragmented ore with respect to all of its perameters (size, iron content, etc.). Ore standardization is carried out through its orderly loading and unloading into and from the bunker. This can be done only with the aid of an automatic system which will permit the uninterrupted feeding of the ball and roller mills and a high coefficient of bunker filling.

The YuGOK has also installed a system for regulating parabolic bunker loading based on instruments of the GR type. The bunkers are filled in the shuttle carrier stage of automatic conveyor operation. The first sections to be filled are those in which the ore level is less than 4 meters. When all sections have been loaded up to this level, the bunkers are automatically filled up to the 10 meter mark. Thus, the automatic bunker loading system consists of the following basic links: 1) middle-and upper-level sensing units in the bunker (4 and 10 meters, respectively); 2) fixed-position sensing units in the loading bin over each section; 3) a block of operating relays in the radiation receiving units; 4) control panels to indicate section filling, position of the loading bin, and system operation; 5) program-selecting equipment.

The automatic loading bin is stopped over each bunker section with the aid of fixed-position sensing units. Each such unit consists of a single STS-5 type counter. The sensing units are positioned along the barrier throughout the length of loading bin travel (figure 3). Each sensing unit is so positioned that each section is loaded symmetrically with respect to the transverse plane. In order to achieve uniform loading, the bin is stopped at two points over each section, resulting in the formation of four symmetrically positioned cones of ore. Such a system makes possible uniform bunker loading and creates the necessary conditions for ore standardization. The ball mills are fed through outlets in each section of the parabolic bunker; the outlet spouts are powered by a command electropneumatic device of the KEP-12K type which turns on the motors only when a particular bunker section is filled with ore; if there is no ore in the section, the power supply is cut off.

γ-electron relays are employed in the agglomeration plant of the Combine to maintain a layer of protective material along the conveyor belts. The absence of this material leads to direct contact between the belt and a residue heated to a temperature of approximately 600 deg-

rees C, which burns through the former. The use of -electron relays has made it possible to eliminate such mishaps.

The Soviet Union is presently conducting studies directed toward the creation of radiometric devices and apparatus which could be used in solving a number of problems involved in mine atmosphere control. Thus, for example, the Central Scientific Research Laboratory of the State Mine Technical Inspection Service (Gosgortekhnadzor) of the RSFSR has developed a portable methanometer which makes it possible to detect the presence of hazardous quantities of methane gas in the mine atmosphere.

2. Metallurgy, Machine Building, and Chemistry

Radiometric methods and devices, as well as various radioactive isotopes and nuclear radiation sources are being employed in the solution of varied problems in metallurgy such as increased metal production and improved metal quality, the finding of methods for improving the strength of metallic structures, developing new metallic materials, automating aggregates and processes, and controlling production.

In ferrous metallurgy, radiometric methods are employed to control the movement of materials in the molten state, the temperature of fire-resistant linings, and the coke and agglomerate levels and densities. Studies based on radiometric techniques have made it possible for several factories to improve blast furnace operation. Positive results have likewise been obtained with the use of radioactive isotopes in the search for more effective techniques for pig iron desulphurization by metallic magnesium and lime-clay slags. Isotopes are employed in studying the blast box in a cupola furnace.

Radiometric probing of the blast portion of a furnace makes it possible to maintain surveillance over the movement of molten materials (an electrically-powered probe is used at the present time). The result of tests of a radiometric installation for controlling blast furnace loading at the Factory imini F. E. Dzerzhinskiy have confirmed the expediency of using this type of equipment in other metallurgical factories. Such a method for controlling loading levels can be employed in the general scheme of blast furnace stoking.

The efficiency of blast furnaces to considerable degree depends upon the preparation of the iron-bearing raw material, and one of the important links in this process involves control over iron ore enrichment and agglomerate sintering. The use of radioactive isotopes in this pro-

cess has also turned out to be effective. A radiometer for determining agglomerate density has been developed at the Kuznetsk Metallurgical Combine. Tests on the equipment run at the agglomerate plant have shown that the introduction of automatic control over the degree of agglomerate sintering will result in an approximate saving of 0.2 million roubles per annum at the Kuznetsk Combine.

At a number of factories, radioactive plugs are used in controlling blast furnace lining wear, thus making it possible to maintain surveillance over the state of the lining while the furnace is in operation. Whereas several years ago such projects were undertaken merely for research purposes, at the present time both the Kuznetsk and Magnitogorsk Metallurgical Combines are employing radiometric methods to control fire-resistant linings. The results of such efforts have made it possible to effect a considerable improvement in the design of blast furnace hearth blocks and wells. Figure 4 shows a scheme for including radioactive isotopes in the hearth block of one of the blast furnaces at the Metallurgical Factory imini F. E. Dzerzhinskiy. The main result of these efforts has been improved blast furnace life and increased savings in maintenance costs.

In the steel industry, radioactive isotopes are most widely used in operations whose basic aim is the improvement of technological levels. The results of a number of such projects have been introduced into practice and yielded considerable benefits. At the Magnitogorsk Combine, radioactive isotopes of iron, sulphur and phospherous were used in the study of slag formation processes, which made it possible to select the most effective procedure for loading molten materials into the 380-ton Marten furnaces. At the Kuznetsk Combine and the "Azovstal'" Factory, radioactive isotopes were used in the study of steel melting vat hydrodynamics. It turned out possible to decrease melting time, as a result of which the steel-producing efficiency of the presently available Marten furnaces increased by tens of thousands of tons without additional expenditures.

The Kuznetsk Combine, Makeyevskiy Metallurgical Factory, and the "Azovstal'" Plant have all worked out radiometric techniques for controlling the wear of fire-resistent Marten furnace lining, thus reducing maintenance time.

Of great interest are the studies carried out at the Kuznetsk Combine and the Stalinskiy Metallurgical Plant on the process of metallic flow during rolling operations. With this purpose in mind, metal ingots were made to include radioactive zones by introducing isotopes into the

mold at various phases of metal crystallization. The method of contact autoradiography can be used to determine the configuration of crystallization zones in the ingot and the depth of deformation zone propagation, as well as to determine the peculiarities of metal flow in the rolling process, which is important for the rational callibration of rollers and the finding of methods to improve rolled stock strength. Figure 5 is an autoradiogram of a rail cross-section obtained by studying the character of metal deformation in the rolling process.

Also promising is the use of radioactive isotopes in chemical laboratories in metallurgical factories for the purpose of improving chemical analysis techniques.

Ferrous metallurgy factories have introduced many automation in control instruments whose operation is based on the use of radioactive isotopes.

At the Factory imini May Day in the city of Kalinin, scientists have worked out and introduced a system for controlling liquid metal levels in semi-continuous molding machine crystallizers. At the present time, continuous steel pouring devices for small cross-section stock are finding ever wider distribution, so that planning organizations are already including such level-controlling devices into their process control schemes. Such a regulator is indispensable in operations involving the rapid pouring of metals, since the operator has no time to watch the metal level in the crystallizer and to control it.

An analagous regulatory system has been introduced at the semi-continuous pig iron pipe installation at the Sinarskiy Pipe Factory.

Also developed and tested is a regulator for controlling liquid metal levels in the crystallizers of continuous steel pouring machines of the conveyor type (URU-6) which will make it possible to completely automate the pouring operation.

Ferrous metallurgy plants are employing radiometric gauges for measuring the thickness of hot and cold rolled stock. The use of thickness gauges to measure stock thickness during the cold rolling process improves the quality of the stock, increases rolling speeds, reduces stoppages, and yields great savings. Thus, on the basis of imcomplete data, a single 12-roll mill will yield a saving of 70,000 roubles per annum (an extremely conservative figure) when furnished with the new equipment. Important savings can also result from the installation of thickness gauges in hot sheet rolling mills. At the present time, such devices are being installed at the Izhor-

skiy Plant and the Kuznetsk Metallurgical Combine.

Ferrous metallurgy plants have lately been attaching much importance to the method of γ-defectoscopy, which makes it possible to control welded seams in inaccessible places, as well as under workshop and assembly conditions. In 1952, the first γ-control sections were organized at the Kuznetsk and Magnitogorsk Metallurgical Combines. At the present time, dozens of factories are using this type of equipment to control welded seams in the bottoms of steel-pouring ladles, tanks, pipes, blast furnace jackets, etc. Systematic control is likewise maintained over the quality of boiler maintenance and casting work.

Great perspectives are being opened up in the field of γ-defectoscopy by the use of electron-optical transformers which will make possible a considerable improvement in the control of such products as large-diameter welded pipes, etc. Work completed in recent years has yielded results which satisfy the basic demands of industry.

In non-ferrous metallurgy, radioactive isotopes are used in developing control methods, studying the mechanisms and kinetics of various processes, and investigating the distribution of microscopic impurities in metals and alloys.

The use of radioactive isotopes has made it possible in a short time to develop and improve techniques for obtaining a number of non-ferrous and rare metals in a highly pure state. Thus, radioactive isotopes were employed in the development of methods for obtaining highly-pure zinc, lead, nickel, and other metals; these methods are presently being employed at the "Ukrtsink" and certain other factories.

Studies have been completed and recommendations submitted for improving the technology of electrolytic copper refining with a minimal contamination of the cathode copper by noble metals, the electrolytic production of zinc with a high yield per unit of current consumed, and the separation of rhenium and molybdenum. Radioactive isotopes have been used to study the interaction of metals with electrolytes in aluminum electrolysis and to establish the reasons for reduced yield per unit of current expenditure in magnesium electrolysis (at the expense of the anode dissolution of the pig iron block). Methods have been worked out for controlling indium distribution in the hydrometallurgical processing of sublimate encrustations obtained in non-ferrous metallurgy plants.

The use of radioactive isotopes has made it possible to improve existing methods and to work out newtechniques

of chemical and spectral analysis in detecting extremely small quantities of foreign matter (zinc, lead, tin, antimony, arsenic, phospherous, germanium, gallium, selenium, tellurium, nickel, cobalt, iron, silver, and a number of other metals) in pure metals.

Radioactive isotopes have been used as indicators in studying the mechanism involved in the sintering of clay-containing furnace charges and the kinetics of certain reactions, in the investigation of the distribution of individual components during the shaft furnace melting, conversion, electrical melting and fire refining of non-ferrous metals, as well as in the study of the distribution of various components in electrolytic processes and processes involved in obtaining and purifying metals and alloys.

Research work involving radioactive isotopes has yielded significant theoretical and practical data which make possible a more correct evaluation of technological processes employed in non-ferrous metallurgy, better control over them, and the determination of ways for their improvement.

In the machine building industry, radioactive isotopes have found the widest application in the defectoscopy of metal products. In many factories the γ-defectoscopy technique has become an inseparable part of the technological process. It has been introduced at over 100 enterprises in our country which are now employing 2000 - defectoscopes. The use of this method in industry yields great savings. Thus, for example, the introduction of γ-defectoscopy at the Taganrog Boiler Factory has resulted in an annual saving of 22.9 thousand roubles due to decreased rejection rates. The Dnepropetrovsk Metal Equipment Factory and the "Russkiy Dizel'" Plant have achieved savings of 68.6 thousand and 14 thousand roubles, respectively.

Extensive economies have also resulted from the wide use of radioactive isotopes in control and automation. In their casting operations, machine building factories can make use of many of the tools and techniques worked out specifically for the metallurgical industry.

There have been a number of suggestions for the introduction of isotope instruments into die stamping operations For example, the Moscow Automobile Plant imini Likhachev, the Physics Institute of the Latvian SSR Academy of Sciences, the Moscow Machine Instrumentation Institute, and the Tallin Control-Measurement Instrumentation Factory developed press locking devices using a strontium β-radiation source dispersed in an enamel coating.

Radioactive isotopes are employed for the study of material, machine, and mechanism wear, making it possible to observe the deterioration process and the transfer of metal from one friction surface to another; it can be used to determine the actual contact area between two adjacent surfaces, to study the role of lubrication in the friction process, etc.

A number of scientific research institutes have carried out studies of cutting instrument wear. The method of marked atoms is highly sensitive, requires little time, considerably simplifies operations, and makes possible a quick selection of proper cutting instrument material.

The use of radioactive isotopes and nuclear radiation considerably widens the boundaries of the practical possibilities of chemistry and physical chemistry. Studies of the effects of nuclear radiation on chemical substances and processes constitutes the subject matter of a new field in chemical science--radiation chemistry. The theoretical possiblity of controlling the course of chemical transformations by means of radiation has now been established and is of great practical importance.

Highly-effective radiochemical processes (polymerization, halation, etc.) which require energy expenditures only for their initiation, can be realized on industrial scale by using powerful sources of ionizing radiation.

The vulcanization of rubber by radiation results in the formation of rubber products, including tires, which differ both in structure and properties from ordinary rubber goods. They are characterized by improved durability, stability in the presence of high temperatures, oils, and chemically aggressive media, and greater strength under the influence of numerous deformations. The Physical Chemistry Institute imini Karpov and a number of other organizations have demonstrated the possibility of vulcanizing rubber by means of radiation without the addition of sulphur. The resulting rubber has great thermal stability, which is particularly important in the case of the thiocols. Also promising is the radiation techniques for obtaining graft copolymers and the technique of binding various polymers by radiation.

No less important are the processes of radioactive halation, i.e., the introduction of chlorine, bromine, boron, and iodine atoms into the molecules of the various substances which is now widely employed in chemical technology for the production of toxic chemicals.

The radioactive technique of obtaining hexachlorane has a number of advantages over the photochemical techni-

que.

Nuclear radiations make it possible to increase the effectiveness of catalytic processes. Methods are being worked out for the radiation-thermal cracking of hydrocarbons for the purpose of improving end-product yields. Radiation-thermal cracking of petroleum and chemical raw materials can proceed at significantly lower temperatures than ordinary thermal cracking, and in addition requires no catalyst. Considerable savings can result from such a promising technique.

The introduction of new types of synthetic fibres and rubbers, as well as increased machine speeds in textile mills and other industries which handle dielectric materials involves the accumulation of quite large electrostatic charges on the material being treated; these result in high rejection rates and are dangerous as fire-and explosion-causing agents.

Air ionized by radiation becomes electrically conductive; this is important for combating electrostatic charges in the artificial fibre, textile, motion picture, paper, rubber, printing and certain other industries.

In the chemical industry, radioactive isotopes and nuclear radiation are finding wide application in automation and control devices. Mass-produced densitometers are used for the automation of a number of processes; the automation of control over the concentration of the salty acid formed through the absorption of hydrogen chloride by water; the regulation of the intermediate lyes and caustics, the drying of electrolytic lyes, the regulation of gaseous chlorine drying processes, etc. γ-densitometers are used to control the movement of petroleum products through pipes from one processing stage to another.

The application of radiometric methods as a means of controlling chemico-technological processes simplifies the solution of various technical problems and curtails the time necessary for investigating various processes.

The method of radioactive indicators is being widely used in tests involving the evaluation of fuel and lubricating materials. Studies are being made of oils and fuels from the standpoint of their sediment-forming potential and the mechanism involved in the effects of admixtures on lubricants. Also of practical interest is the possibility of employing radioactive indicator methods under factory conditions for evaluating the quality of lubricants, admixtures, and fuels, as wells as the effectiveness of neutralizing oil admixtures, the lacquer-forming properties of oils and admixtures, and their corrosive aggressiveness. Significant advances have like-

wise been made in activational analysis methods for minute traces of various elements.

Extremely promising is the use of radioactive isotopes for the purification of industrial gases. By ionizing waste industrial gases with the aid of radioactivity, it is possible to create proper conditions for the coagulation and subsequent removal of tiny fractions of dust from these gases; this in turn will make it possible to make practical use of the dust and to purify the atmosphere both within the plant and the surrounding populated areas.

3. Research in the Field of Physical and Technical Sciences.

The significance of utilizing advances in nuclear physics in the various fields of science and technology consists mainly in the fact that we have developed a fundamentally new technique of studying various processes taking place in matter and the properties of matter itself. Thus, new possibilities have opened up for deeper study of various laws which determine the behavior of substances under different conditions. This in turn is a contributing factor to the acceleration of technical progress. With reference to the development of a number of scientific fields, the possibility of extensive use of atomic reactors and accelerators for research purposes is of decisive importance. Physicists and technicians now have at their disposal a whole series of research atomic reactors specially designed for various specialized purposes in many of the scientific technical centers of our country (Moscow, Leningrad, Kiev, Tbilisi, Tashkent, etc.). The work schedules for these reactors include many important scientific problems. In various fields of science, important research programs have been and are being carried out using radioactive and stable isotopes.

Radioactive isotopes are finding wide application in the solution of problems involving the development of new types of steel and alloys, as well as the investigation of the basic laws of their thermal processing. New data have been obtained by studying the diffusion, distribution of elements and interatomic interaction in metals and alloys.

Diffusion studies have yielded results which make it possible to establish serveral laws having to do with the level of diffusive mobility of various metals and peripheral diffusion, as well as donor-acceptor atomic interaction in solid solutions. Of special importance are

the results having to do with the micro-distribution of admixtures and binding elements in alloys based on titanium and zirconium now coming into wide use in the atomic industry. It has been shown, for example, that the heat resistance and resistance to corrosion of zirconium alloys to a considerable degree depends on the presence of large concentrative heterogeneities at the sub-boundaries which arise as a result of interactions.

The Institute of Metal Studies and the Physics of Metals under the Central Ferrous Metals Scientific Research Institute, Moscow State University, the Moscow Steel Institute, and other scientific agencies are engaged in studies on the determination of the saturated vapor of various alloy components. Already studied are the iron-carbon, iron-chromium, nickel-chromium, etc. The resulting data on vapor elasticity have made possible more comprehensive thermodynamic analysis and a clarification of certain peculiarities of interatomic interaction in solid solutions. The successful development of these thermodynamic studies is due in large measure to the application of radioactive isotopes, which are an important experimental tool in this area. The research program involves the use of radioactive isotopes of iron, chromium, nickel and many other elements.

In the field of radiation physics, there have been significant developments in such important fields as the study of the action of nuclear radiation on the properties of structural and semi-conductor materials, the investigation of the physical nature of radiation effects, the study of the mechanism involved in the interaction of radiation with matter, as well as the radiation treatment of solid bodies for researches having to do with the improvement of our concepts about the mechanism of the action of various factors on the properties of solid bodies (strength, electrical conductivity, plasticity, electrical and magnetic properties). Such work is now going on at a number of scientific institutions under the USSR Academy of Sciences and Republican Academies. Date resulting from the most important of these studies have appeared in periodicals and have been presented at international conferences on the peaceful uses of atomic energy. They have promoted the development of atomic power production and other important technological areas. As a result of research carried out by the USSR Academy of Sciences, we are now familiar with certain individual details of processes taking place in metals during irradiation. Of practical interest are data on the effects of metal irradiation by high-energy particles, as well as analagous studies on

semi-conductors and magnetic materials.

Of great importance in solid state physics is the possibility of strengthening metals by irradiation. In this area, the primary role is played not by the practical use of radiation to strengthen metals, but rather by new possibilities in the study of the physical properties of existing high-strength metals.

At the present time, we are familiar with several methods of strengthening metals. In particular, the strength of puremetals and alloys can be significantly increased by thermo-mechanical treatment. According to existing concepts, plastic deformation brings about the strengthening of metals by giving rise to structural defects largely in the boundaries of friction between individual crystals. This is accompanied by extensive kernel fragmentation and a number of other accompanying phenomena which complicate the study of the mechanisms involved in the strengthening and weakening of metals.

Irradiation likewise results in the formation of defects in crystaline structure which are different, however, than those arising in plastic deformation. Radiation defects appear under definite conditions without any fragmentation of the metallic crystals, and are in general features comparable to the fine-dispersion products formed in dispersive solidification. The strengthening of metals by irradiation is determined by the fact that dislocations experience added resistence to their movements as a result of interaction with the radiation defects. Attempts have been made to use these concepts in explaining such metal properties as variation of the internal friction level and the elasticity modulus, the raising of the viscosity limit, and a number of other effects characteristic of irradiated bodies. But all of these assumptions frequently bear an extremely general character the reason for which lies in the insufficiency of our knowledge of the physical nature of radiation effects and the mechanism involved in their interaction with dislocations and other structural defects.

It should be noted that much data has appeared in recent years on alterations in solid bodies due to irradiation. But these data do not always make it possible to form a clear concept of the nature of radiation effects and the mechanism of their behavior in solid bodies. This is partly due to the fact that the irradiation of metals is usually conducted in complex fields (neutrons, as well as α, β, and γ – radiation), and with the use of strong doses of radioactivity. For this reason, studies conducted over the last few years have concentrated on the

action of small doses of homogeneous radioactivity using such sensitive research tools as internal friction.

Scientists in the Soviet Union obtained the first comprehensive set of data on the effect of the preliminary irradiation of austenitic steel by fast neutrons on martensitic transformation.

The Institute for Metal Studies and the Physics of Metals under the Central Ferrous Metals Scientific Research Institute in cooperation with the Theoretical and Experimental Physics Institute has carried out extensive experimental programs on the study of metals by metallic alloy neutronography (the study of interatomic interaction, atomic ordering in magnetic alloys, structural alterations under the action of high pressures, etc.). Figure 7a,b shows a neutron crystal spectrometer, while Figure 8 contains a diagram of the set up used in the neutronostructural analysis program. Research in this area has served to confirm that large monocrystals of iron-nickel alloys grown from the molten mixture, both of the binary type and those bound by third element, consist of fragments disoriented with relation to one another in approximately the same degree as the tiles in a mosaic. Various fragments of one and the same monocrystal can differ from one another significantly in the degree of mosaic character. Results obtained in this work are of interest both to crystal growth theory and from the standpoint of improved neutronostructural analysis methods.

Of great significance to the development of new magnetic alloys is the study of the atomic ordering in solid solution. By studying the magnetic portion of neutron dispersion, detailed studies were carried out on atomic ordering in iron-nickel alloys of the permalloy class of high magnetic permeability. Direct data were obtained on the existence of a superstructure in the Ni_3Fe compound and the effects of a third element (copper, chromium, or molybdenum) on that superstructure. An analysis of the results made it possible to render a more precise diagram of phase equilibrium in iron-hickel alloys and to draw an important conclusion about the special ferromagnetic nature of the energy of atomic ordering in these alloys.

Other systems in which atomic ordering plays an important role in thermal processing are the iron-cobalt magnetic alloys which are also extremely important due to their high magnetic saturation. Neutronographic data on these alloys made it possible to establish the presence of an anomalously wide concentrative region for the existence of a superstructure in the equiatomic FeCo com-

pound, and lead to the conclusion that transformations from the ordered to the disordered state in the iron-cobalt system are to be regarded as second-order phase changes. Figure 9 is a neutronogram of an iron-cobalt alloy.

The Central Ferrous Metal Scientific Research Institute has completed a theoretical study having to do with a calculation of neutron defraction by austenitic crystals Contrary to the opinion of certain foreign scientists, it has now been proved that it is possible to determine the position of carbon atoms in the crystal lattice of austenitic steel. The experimental portion of the program was carried out at the First Atomic Electrical Power Station (USSR). The results obtained have confirmed the concept of the octahedral varient for carbon atom locations in the austenitic crystals.

In conclusion, it should be noted that possibilities for the rational use of isotopes and nuclear radiation in science and technology are far from exhausted. It is one of the timely tasks of physicists to find new ways of employing isotopes in scientific research and industry. It is to be expected that new results of fundamental scientific and practical significance will be obtained in the field of applied nuclear physics in the very near future.

Received 20 July, 1961

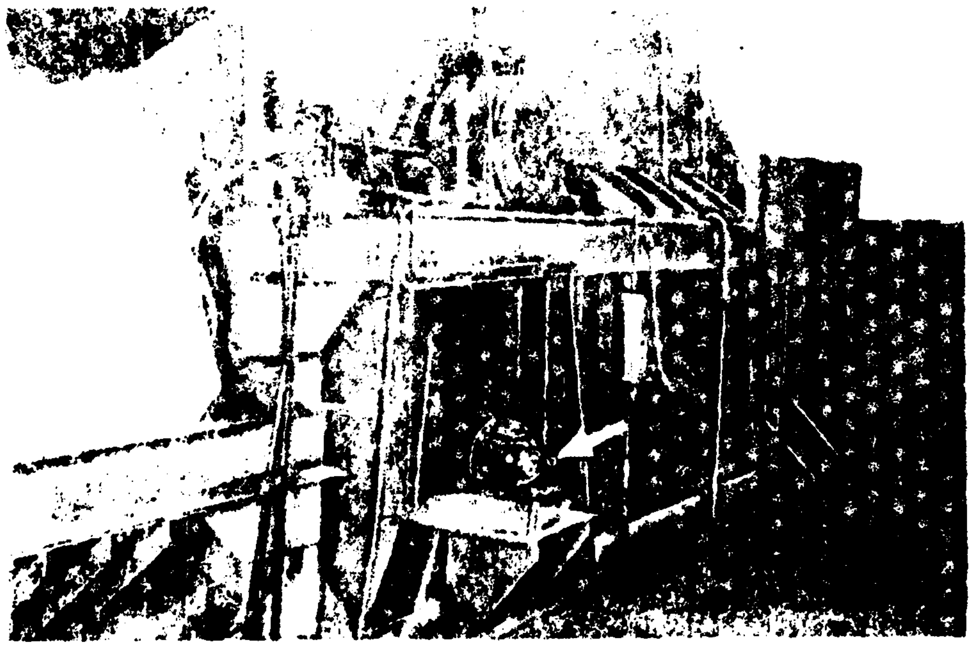

Figure 1. Container with radiation source of γ -electron relay on reloading line (indicated by arrow).

Figure 2. γ-electron relay receiver mounted on medium coarse ore crushing conveyor (indicated by arrow).

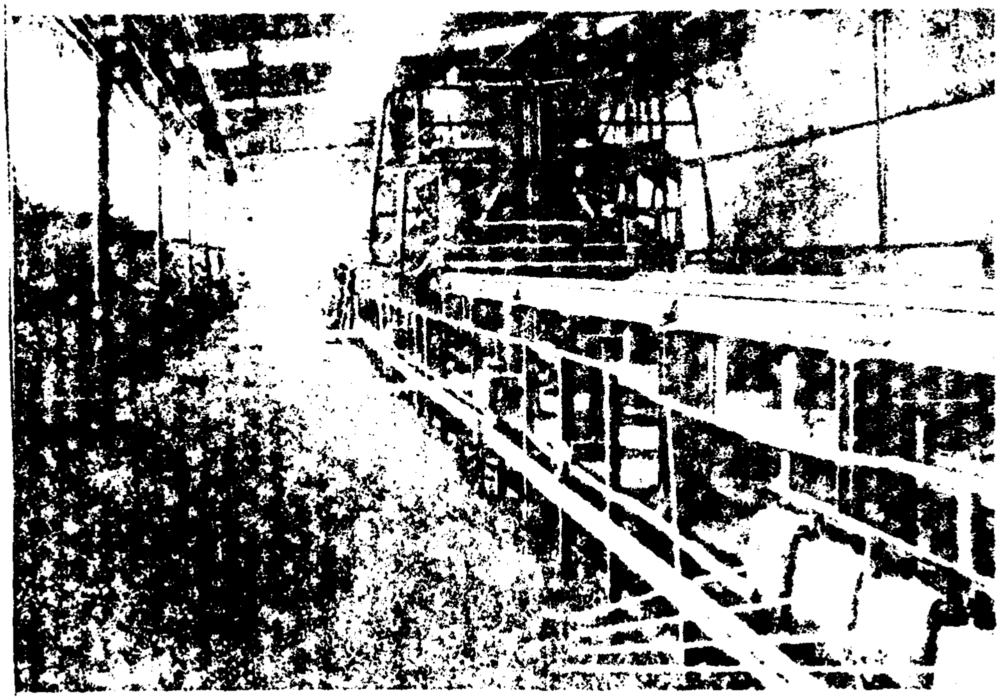

Figure 3. γ - electron relay receivers mounted on parabolic bunker guard railing, used in controlling automatic conveyer line (indicated by arrow).

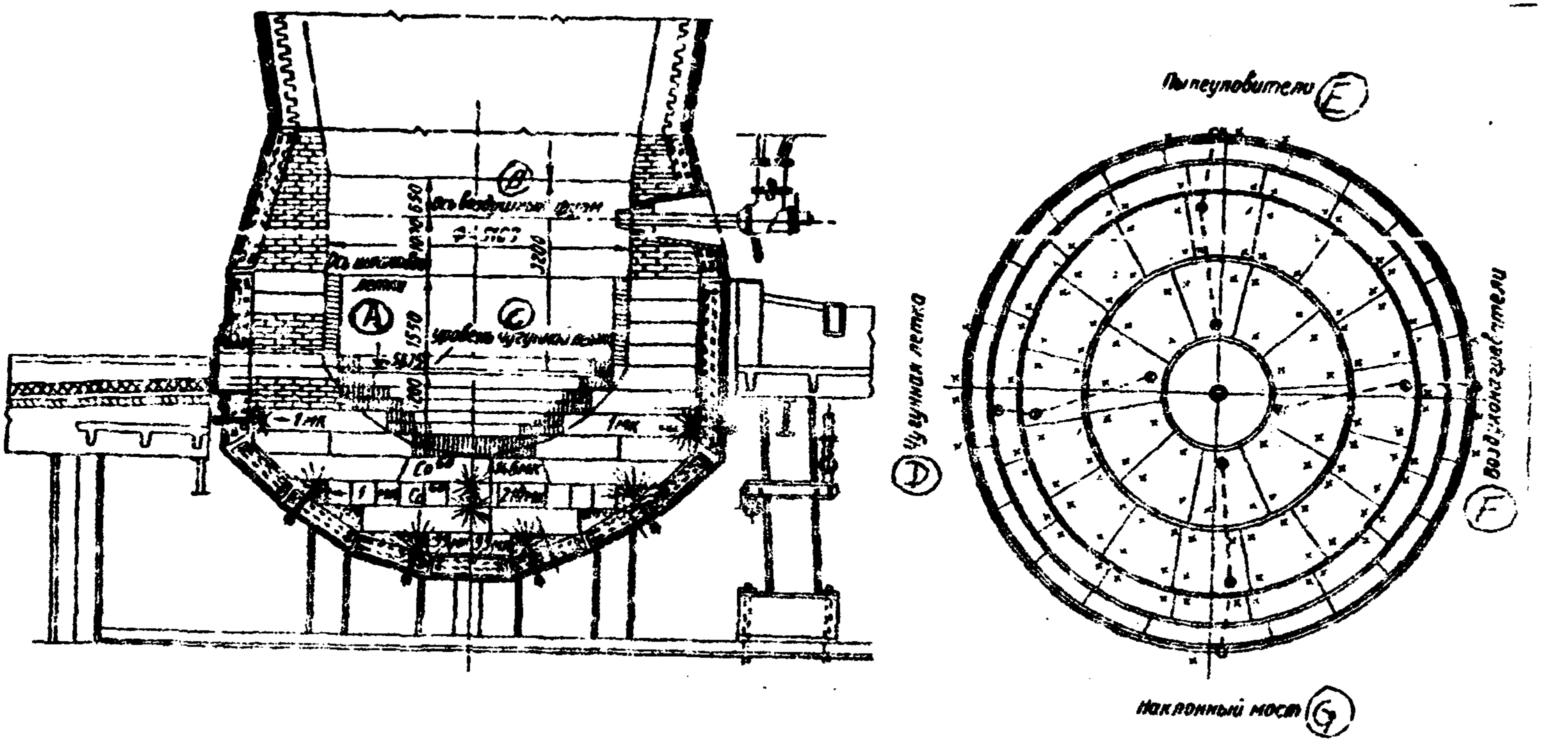

Figure 4. Scheme of isotope loading into blast furnace well.
A = Tap hole axis;
B = Air tuyere axis;
C =Level of pig iron tap hole;
D = Pig iron tap hole;
E = Dust removal ducts;
F = Air heaters;
G = Inclined bridge;

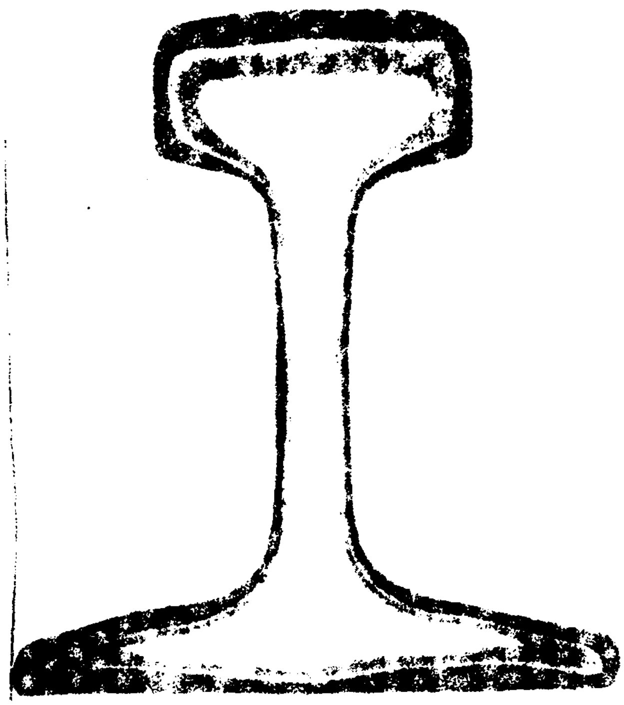

Figure [illegible]. Autoradiogram of rail beam.

Figure 6. Autoradiogram of Zr-C system (X 56).

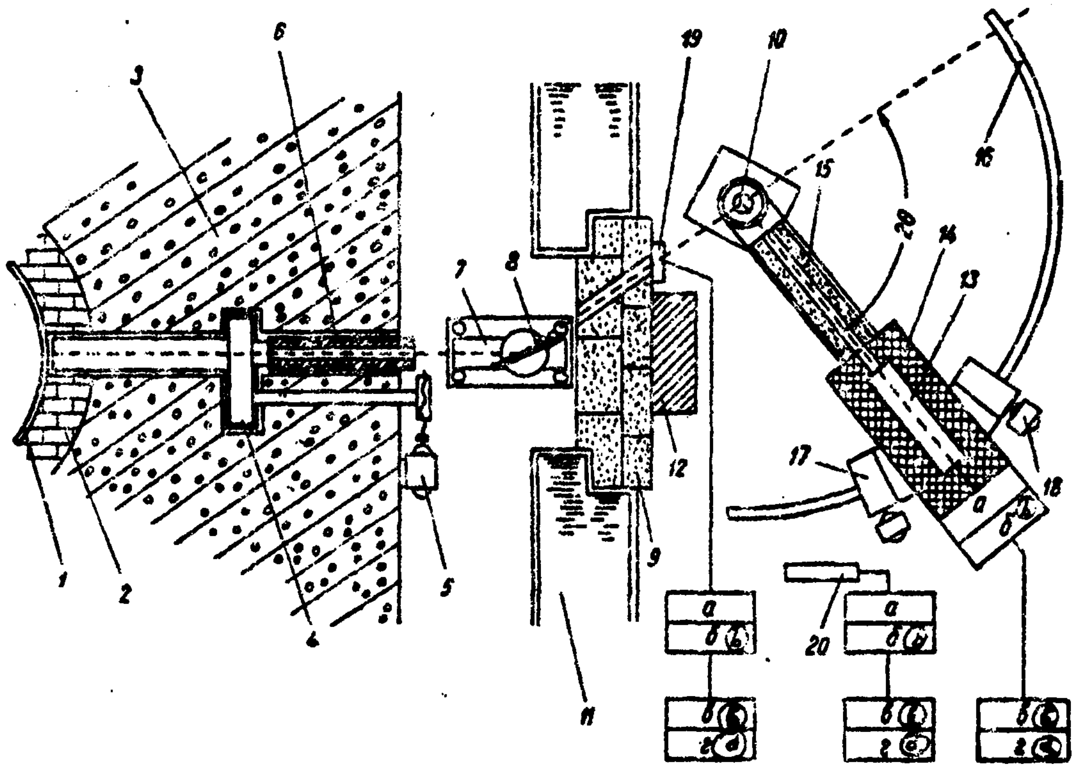

Figure 8. Diagram of installation for neutron structural analysis.

1 -- Reactor tank walls;
2 -- graphite reflector;
3 -- Concrete shielding;
4 -- Gate valve;
5 -- Gate valve motor;
6 -- Plug with slit collimator;
7 -- Monochromator crystal unit;
8 -- Lead crystal;
9 -- Shielding of boron-containing material;
10 -- Sample;
11 -- Shielding tanks with water;
12 -- Steel gate;
13 -- Spectrometer detector;
14 -- Detector shielding;
15 -- Screening box;
16 -- Spectrometer support rail;
17 -- Electric motor amd reducer of operating assembly;
13 -- Selsyn motor to operate deflection meter remotely;
19 -- Counter-monitor;
20 -- Background level counter;
a -- linear pulse amplifiers; b -- amplitude discriminators; c -- scaling devices; d -- mechanical counters (last two elements mounted on control panel).

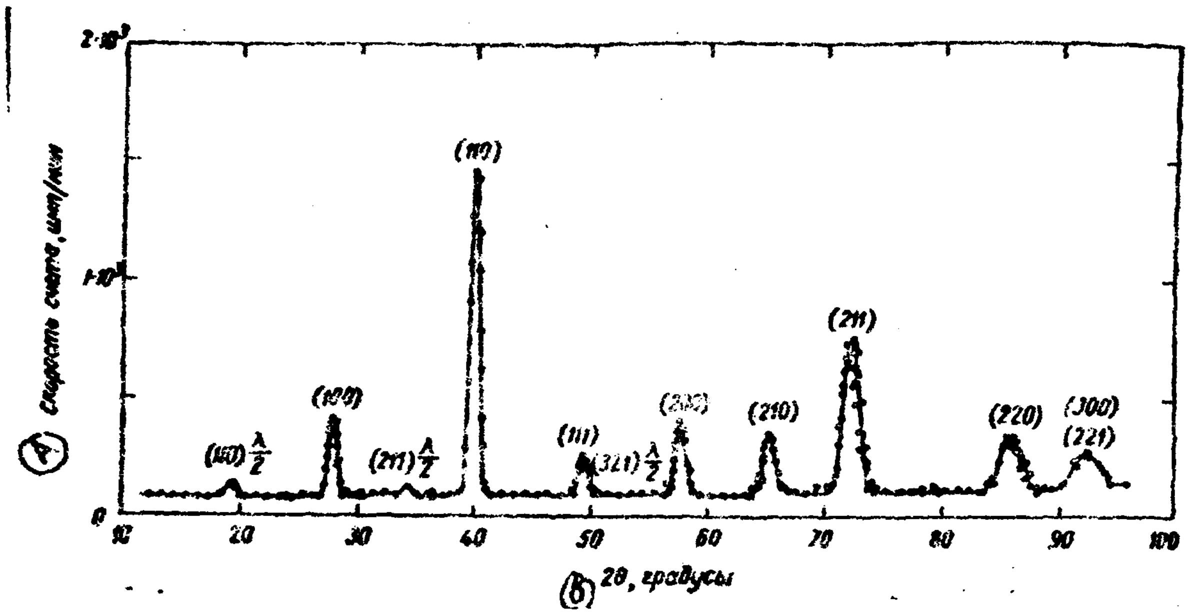

Figure 9. Fe-Co Neutronogram; A = Counting rate, pulses/minute; B = 2Θ, degrees.

A REVIEW OF GOSATOMIZDAT BOOKS FOR 1960-1961

/Following is the translation of an unsigned series of items in Atomnaya Energiya (Atomic Energy), volume 11, # 4, October 1961, pps. 404-415./

What follows is a survey of publications on nuclear power production and allied scientific and technical fields issued by Gosatomizdat in 1960-1961. However, due to the scientific and practical value of many of the materials included in the Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, (Geneva 1958), it was decided that these volumes should also be included in the present survey.

The literature considered in the survey is grouped according to five subject headings: "Nuclear Physics", "Nuclear Power Production", "Nuclear Fuels and Materials", "Protection from Nuclear Radiation", and "Radioactive and Stable Isotopes".

In a few cases, certain deviations from the scheme have been permitted. Thus, for the readers' convenience, publications on radiation protection in reactor installations have been included in the "Nuclear Power Production" section. At the end of the survey there will be a description of three popular scientific works particularly noteworthy for their comprehensiveness and character of presentation.

Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy (Geneva 1958).

/Note 1: Gosatomizdat is the State Publishing House for Literature in the Field of Atomic Science and Technology. Its former name was the Publishing House of the Main Administration on the Uses of Atomic Energy under the USSR Council of Ministers./

/Note 2: the Proceedings of the Second Geneva Conference consist of a 6-volume set of papers by Soviet scientists and a 10-volume set of selected papers by foreign scientists./

NUCLEAR PHYSICS. Papers on the physics of nuclear power production are collected in volume 1 of the reports by Soviet Scientists, Nuclear Physics, and Volumes 1 and 2 of the selected papers by Soviet scientists entitled The Physics of Hot Plasma and Thermonuclear Reactions and Neutron Physics. The first part of the volume Nuclear Physics deals with plasma physics and the problem of controlled thermonuclear reactions; it opens with a survey report by Academician L. A. Artsimovich on research in this field going on in the Soviet Union. The other papers contain the results of studies on high-voltage pulsed discharges. A series of reports has to do with the problems of plasma stability, the stabilization of plasma with the aid of heterogeneous magnetic fields, and the constriction of plasmas by high-frequency electromagnetic fields. Also of interest was a paper on plasma radiation in a magnetic field. One of the reports contains a theoretical analysis of the problem of simple and shock magnetohydrodynamic waves. Much attention is deveoted to experimental methods of studying plasma perameters. The second part of the volume includes papers on nuclear physics and certain problems of charged particle acceleration: the initiate of operations on the synchrophasotron, Soviet studies of cosmic rays with the aid of rockets and artificial earth satellites, nuclear heavy-ion reactions, nuclear fission asymmetry, neutron radiation capture cross-sections, etc.

The volume Hot Plasma Physics and Thermonuclear Reactions contains both full texts and summaries of reports. Several survey reports deal with the development of thermonuclear research in the capitalist countries. Most of the papers have to do with the problem of plasma configuration stability, as well as the theory of plasma heating with the aid of electromagnetic fields and shock waves. Many papers contain detailed descriptions of devices and experimental results on installations with various methods of plasma heating and capture (toroidal systems, stellarators, magnetic traps, etc.). Several papers include surveys of measurement techniques used in studies on controlled thermonuclear reactions in Great Britain and the US.

The volume entitled Neutron Physics is partially composed of survey reports on the basic problems of neutron physics. The papers in this volume can be classified ac-

cording to the following categories: neutron structure and properties; cross-sections of neutron interaction with matter, including structural materials employed in reactors; nuclear fission, fission products and radiation; resonance capture; neutron retardation; neutron thermalization; modern methods and techniques for measuring neutron cross-section, streams and neutron spectra. All of these categories encompass a large body of theoretical and experimental material.

NUCLEAR POWER PRODUCTION. This section includes: volume 2 of the papers by Soviet scientists entitled Nuclear Reactors and Nuclear Power Production, and volume 3 and 4 of reports by foreign scientists, Nuclear Reactor Physics, and Nuclear Reactors and Nuclear Power Production The first part of volume 2 deals with Soviet atomic power production installations, while the second describes experimental and test reactors, as well as experiments and research conducted with this equipment for the purpose of improving reactors. The third part, largely theoretical, deals with the problems of reactor physics. It also includes questions having to do with reactor design methods.

Volume 3 consists of three parts. The first covers experiments on the study of various types of reactor grids as well as several types of reactors and reactor systems. The second part deals with the problems of reactorphysics and questions relating to theoretical, reactor, neutron, and mathematical physics. The third part contains descriptions of reactor kinetics, fuel cycle calculations, and reactor safety problems.

Volume 4 contains descriptions of the basic types of foreign power production reactors and atomic electrical power stations. It also deals with the economics of nuclear power production and nuclear reactor applications not related to the exploitation of chain reactions for power production purposes.

NUCLEAR FUELS AND MATERIALS. This section is made up of volumes 3 and 4 of the papers by Soviet scientists Nuclear Fuels and Reactor Metals, The Chemistry of Radioactive Elements and Radiation Transformations, and volumes 5, 6, 7, and 8 of the selected foreign papers, The Chemistry of Radioactive Elements and Radiation Transformations, Nuclear Fuels and Reactor Materials, The Technology of Atomic Raw Materials, and The Geology of Atomic Raw Materials.

The first part of volume 3 deals with materials having to do with the geology, minerology, prospecting,

enrichment, and reprocessing of atomic raw materials. The second part deals with problems in metallurgy, metal studies, and technology as they relate both to nuclear fuels (uranium and its compounds, thorium, plutonium), and a number of structural materials (zirconium, berylium, and their alloys). It also includes results of studies on the physical and corrosive properties of reactor metals and the effects of neutron irradiation on the structure, properties, and dimensional stabilization of the fuel, i.e., the results of investigations of many of the most important problems in modern metal studies.

Volume 4 of the papers by Soviet scientists covers modern methods of reprocessing irradiated nuclear fuels and contains results of studies on the chemistry of ruthenium, thorium, uranium, plutonium and americium. Also treated are the problems involved in radioactive waste sorption and burial. Several papers are devoted to individual problems in radiation chemistry.

The papers in volume 5 of the selected reports by foreign scientists deal with the problems in the chemical reprocessing of irradiated materials, analytic control methods, methods of removing and disposing of radioactive wastes, as well as several problems in the radiation chemistry of polymers, gases, water solutions, and both solid and liquid organic compounds.

Volume 6 includes a number of papers on the metallurgy of uranium and its alloys, the metallurgy of niobium and structural materials, the metallurgy of uranium, uranium alloys, and plutonium, the physical, thermodynamic, and corrosive properties of uranium, plutonium and the alloys and compounds. Also considered are the problems involved in the effects of neutron irradiation on nuclear fuels and structural materials, as well as questions having to do with the technology of heat-producing elements manufactured.

Volume 7 includes selected papers by foreign scientists having to do with the technology of atomic raw materials. This volume has five sections: "The Leaching of Uranium and Thorium from Ores and Their Precipitation from Solutions"; "Sorptive Methods of Extracting Uranium for Solutions and Pulps"; "Extractive Methods of Removing Uranium and Thorium from Solutions and Pulps"; "The Preparation of Pure Uranium and Thorium Compounds"; "The Preparation of Uranium Hexafluoride and its Reduction into Tetrafluoride".

Volume 8 of the selected reports likewise contains five parts. The first has to do with general problems in the geology, geochemistry and minerology of uranium and

thorium; the second is made up of 10 regional surveys of the present state of the uranium and thorium resources; the third contains descriptions of individual uranium and thorium deposits; the fourth covers methods and techniques for surveying and prospecting for uranium and thorium; the fifth deals with beryllium and zirconium geology.

RADIOBIOLOGY. Volume 5 of the reports by Soviet scientists entitled Radiobiology and Radiation Medicine deals with four groups of problems. The first group has to do with the peculiarities of the biological effects of ionizing radiation, long-range effects of radiation in small doses and genetic radiation effects, as well as several problems involved in the treatment of radiation sickness. The second group of papers has to dowith the use of radioactive isotopes in biological and medical research; the third is concerned with the application of atomic energy in medicine. The fourth group is made up of papers dealing with the absorption by soils of certain groups of uranium fission products and their gradual accumulation in plants and food products.

Volume 9 of the selected papers by foreign scientists which bears the same title as volume 5 of the Soviet collection contains papers on six topics: the biological effects of radiation, protection against irradiation; work hygene at atomic industrial enterprises; the use of the method of marked atoms in biochemistry and physiology: the applications of atomic energy in medicine; radiation genetics.

RADIOACTIVE AND STABLE ISOTOPES. Volume 6 of the papers by Soviet scientists opens with a paper entitled The Use of Radioactive Isotopes in the USSR in which the author presents a detailed survey of the present state of efforts in the use of isotopes in the national economy. Two reports in this volume deal with the problems of preparing materials for irradiation, the irradiation of various samples, the reprocessing of irradiated materials, and the development of methods for remote work in radiochemical laboratories.

The four following papers have to do with the applications of radio isotopes in industry and technology. Five papers deal with individual problems in dosimetry. The last eleven reports have to do with various aspects of the use of radioactive isotopes and ionizing radiation in agriculture. They describe the results of studies of photosynthesis with the aid of quantitative radiometric methods for investigating the conveyance, distribution,

and transformation of certain physiologically active substances within the plant, the absorption of phospherous by agricultural plants as determined by their resistance to cold, the use of radioactive isotopes in the study of plant protection, etc.

Volume 10 of selected reports by foreign scientists entitled The Preparation and Use of Isotopes consists of four parts. The first of these has to do with several methods of preparing stable and radioactive isotopes, techniques for synthesizing marked organic compounds, radiochemical installations for the production of isotopes from uranium fission products, and methods for producing radioisotopes of high specific activity; the second part is devoted to designs for installations and instruments employing radioactive isotopes; it contains a number of interesting examples of radio isotope application; the third part contains descriptions of apparatus and methods of registering ionizing radiation; the fourth encludes descriptions of laboratories and equipment for work with radioactive materials.

Nuclear Physics

(Nuclear Physics, Neutron Physics, Nuclear Research Methods).

The book by P. E. Nemirovskiy entitled Modern Models of the Atomic Nucleus (1960, 300 pages), is based on a number of Soviet and foreign papers of recent years, including the author's own original articles. In accordance with its title, the book covers the following topics: Shell models; the general or collective model of the nucleus; and finally, the optical nuclear model and its relation to the former. The book concludes with an examination of radioactive transformations in the first two models and the application of the generalized model to alpha decay theory. The author has avoided cumbersome mathematical expositions, and for this reason his book is acceptable to a relatively large number of readers. The bibliography of this interesting book about low-energy nuclear processes contains 300 titles.

N. F. Nelipa's book entitled Introduction to Multiple Scattering Theory, 1960, 159 pages, is based on a series of lectures presented by the author at the Moscow Engineering Physics Institute. Despite the small size of the book, the author has succeeded in describing methods for solving problems involved in the passage of gamma-quanta electrons, and neutrons through matter taking multiple scattering into account. The book considers the sources

of varying geometrical form and includes a number of calculated examples. This work is particularly timely at the present time, especially in connection with the practical necessity of calculating and constructing biologically protective equipment.

Of considerable interest is the collection of articles entitled Apparatus for Nuclear Spectrometry, 1961, 434 pages, edited by S. S. Kurochkin and V. V. Matveyev. The first part of the anthology, which contains four articles, considers spectrometer sensing units in mass-produced apparatus (sintillation counters, photomultipliers, light guides). The second part (seven articles) describes the electronic apparatus of spectrometers (a non-over regulated linear pulse amplifier, a precision mean counting rate meter, a single-channel spectrometer with a resolving time of 0.3 microseconds, etc.) The materials in this collection can be used in other fields of science and technology in the design of various types of control and measuring apparatus.

Special problems in equipment design for nuclear research in cyclotron laboratories are comprehensibly treated in the book by L. F. Kondrashev and N. N. Khaldin entitled Equipment for Nuclear Research, 1961, 148 pages. This represents a generalization of the work experience accumulated by a team of designers and physicists at the cyclotron laboratory of the Atomic Energy Institute imini I. V. Kurchatov under the USSR Academy of Sciences. This is the first book which gives sufficient attention to certain obscure problems in the design, construction, callibration, and operation of special equipment employed in conjunction with the cyclotron in nuclear research, as well as in the adjustment and operation of the cyclotron itself. Many elements of the apparatus described can be used in non-cyclotronic laboratories as well.

A collection of articles entitled Neutron Physics, 1961, 371 pages has recently appeared under the editorship of P. A. Krupchitskiy. It contains original articles by various authors. The four sections which make up this collection deal with the following problems: neutron retardation, resonance absorption, and diffusion (18 articles); fission, fragments, and secondary neutrons (6 articles); interaction of fast neutron with nuclei (12 articles); and gamma radiation in neutron capture (4 articles). The book is of great interest both to theoreticians and engineering physicists, particularly those concerned with the calculation and design of reactor installations.

A recently issued publication of the textbook variety

for higher educational institutions is the Collection of Problems in Atomic Physics by I. Ye. Irodov, 1961, 239 pages, which has already undergone 2 editions. The book contains about 850 problems with sufficiently detailed directions for the solution of the more complicated ones.

Another work which might serve as a text for physics and engineering physics students is Atomic Physics by M. Ware and J. Richards, translated from the English, 1961, which represents an introduction into modern atomic physics. It deals with the atomistic concepts of matter, electricity, radiation, the Rutherford and Bohr models of the atom, the foundations of relativity theory, artificial and natural radioactivity, nuclear reactions, intranuclear energy, elementary particles, and cosmic rays. The appendices contain tables of isotopes, atomic constants, and other reference material. The authors examine the fundamental problems of atomic physics without employing complex mathematical tools and go along way toward filling the need for a book of this type.

Two other recently translated works on nuclear physics are V. Davison's Neutron Transfer Theory from the English, 1960, 520 pages, and Tables on Nuclear Spectroscopy by A. H. Wapstr, G. I. Nijh, and R. Van Lishut from the English, 1960, 178 pages. The book by V. Davison is the world's first monograph giving a full presentation of modern foreign mathematical techniques for solving problems involving neutron dispersion in various media. Some techniques are described in the book for the first time. Translation editor G. I. Marchuk has included a bibliography, footnotes, and an appendix giving the fullest possible information about Soviet research in the same field possible in a first edition. The book of tables on nuclear spectroscopy was intended by the authors to be a brief handbook on α-, β- and γ- spectroscopy, for this reason most of the data are presented in the form of graphs and tables. Brief annotations facilitate the use of this reference work. The first part of the book contains general mathematical tables, atomic constants, and a description of methods for processing experimental results; the latter part contains spectrometer calibration standards. The handbook likewise contains theoretical information. Of special interest are the chapters on nuclear models and angular distributions and correlations.

A special place among books on nuclear physics is occupied by the work of T. A. Yampol'skiy entitled The Neutrons of Atomic Explosions, 1961, 132 pages, and the book Operation "Argus", from the English, 1960, 117 pages. The first of these describes the physical picture of pro-

cesses arising as a result of neutrons produced in an atomic explosion. After an introductory exposion of the foundations of neutron physics, the author discusses the spatial distribution of neutron following aerial and ground explosions, the role of lagging neutrons, -radiation from neutron capture by air, ground activation, and residual radiation from fission fragments. The final chapter discusses problems in explosive neutron dosimetry.

Operation "Argus" was the name given to an experiment carried out in the US in the latter part of 1958 in order to study the behavior of electrons arising as a result of atomic explosions at an altitude of 480 kilometers in the earth's magnetic field. The explosions led to the formation of an artificial electron belt around the earth, which in turn gave rise to such effects as aurorae borealis, radiowave distortion, etc. Observations of the electrons introduced into the earth's magnetic field were carried out with the aid of artificial satellites and rocket probes sent up to an altitude of 800 kilometers. The book Operation "Argus" contains papers presented at a special symposium held in 1959 on the effects of artificial radiation at high altitudes. The material included in this book is of theoretical and practical value to many fields of science and technology.

The popular scientific work by M. A. Bak and Yu. F. Romanov entitled The Neutron, 1960, 82 pages, makes it possible for a wide circle of readers to get acquainted with the discovery and basic properties of the neutron. The book convinces the reader that the neutron is actually an important component part of all nuclei and that it was this particle which was responsible for the rapid growth of nuclear physics. The neutron plays a decisive role in nuclear fission chain reactions and in the liberation of intranuclear energy on an industrial scale.

Of the recently-translated popular scientific works on nuclear physics, the most interesting is Atomic Age Physics by G. Semat and G. White, 1961, 205 pages. The book was written in connection with a popular course of lectures presented to a very wide audience over US television. The first half of the book deals with the atom and its structure, the properties of atomic particles, and the history of their discovery. The second half contains a detailed description of the history of the discovery of the atomic nucleus. A number of chapters deal with natural radioactivity, radioactive disintegration, the splitting of the nucleus, particularly with the aid of charged particle accelerators. The final chapters describe the latest advances in nuclear physics having to do

with the liberation of intranuclear energy through fission and fusion. The book makes it easy for the reader to acquaint himself with the history and development of atomic and nuclear science. It will be useful to the reader regardless of the level of his familiarity with this field of science.

Essentially the same subjects are dealt with in the books by W. Braubeck Measurement Methods in Nuclear Physics, translated from the German, 1960, 87 pages and J. Sharp The Measurement of Nuclear Radiation, from the English, 1961, 78 pages. Both books are based on series of popular articles published in the periodicals Atomkernenergie (Nuclear Energy) and Nuclear Engineering. The books give a brief but comprehensive account of methods used in measuring nuclear radiation. The popular scientific work by J. Jones, J. Rotblatt, and J. Wirrow, Atoms and the Universe, from the English, 1961, acquaints the reader with the foundations of nuclear physics and its application to problems having to do with the structure of the universe. The first chapters contain a history of the discovery and properties of elementary particles, the splitting of the atom and the problem of using intranuclear energy, nuclear reactions in the stars and sun, and cosmic rays. The authors then describe the properties of matter accepted in classical and modern physics as based on relativity and quantum theorgy. A considerable portion of the book deals with the solar system, the generation of energy within the sun, the chemical composition of the planets, the Milky Way, and a discussion of the size and age of the universe. The book is highly readable and accessible to wide reader circles.

THE PHYSICS OF HOT PLASMA AND CONTROLLED THERMONUCLEAR REACTIONS. In recent years, in connection with the problem of controlled thermonuclear reactions there has been a considerable development of plasma studies. This in turn has led to the appearance of books dealing with the theory, creation, and use of plasmas both in relation to the above problem and other fields of science and technology.

The book by V. P. Silin, and A. A. Rukhadze entitled The Electromagnetic Properties of Plasma and Plasma-Like Media, 1961, 244 pages is based on theoretical concepts about media with a spatial dispersion of dielectric permeability (Chapter 1). In the next two chapters the authors present a theoretical description of the properties of isotropic and anisotropic plasma. In the final chapters, there is a generalized presentation of the ef-

fects of spatial dispersion on certain phenomena in metals and an investigation of the dielectric permeability of molecular crystals. The book gives a systematic account of a large number of Soviet and foreign achievements (the bibliography contains 285 titles) and is intended for specializing physicists and engineering physics students.

Also theoretical in its scope is the book by D. L. Synge entitled Relativistic Gas, from the English, 1960, 139 pages. This book might be called an introduction into the kinetic theory of a gas whose particles have velocities comparable to that of light. Such a gas represents the limiting case of a hot plasma. The examination of a relativistic gas is also interesting in connection with the idea of a photonic rocket for space flight purposes. The exposition is based on classical concepts, without the use of quantum mechanics, and rests on the geometric interpretation of the special theory of relativity.

The book by S. Brown Elementary Processes in Gas Discharge Plasmas, from the English, 1961, deals with problems of great interest to plasma research. The book is based on a series of lectures presented at the Massachusetts Institute of Technology and technical reports submitted to the Electronics Research Laboratory. In scope the book is very similar to other works on gas discharges, although it does contain an unusually large number of figures and tables included largely in the chapters dealing with transverse cross-sections, elastic collisions, recharging, and diffusion.

Many of the important concepts presently employed in plasma research are borrowed from cosmic electrodynamics. The foundations of plasma physics as applied to cosmic phenomena are presented in Space Electrodynamics by J. Danjey, from the English, 1961, 205 pages. Its contents are based on results obtained by the British school of astrophysicists. This work is intended for the advanced reader who will find in it a new and interesting exposition of many famous problems.

Project Sherwood by A. S. Bishop (1960, 175 pages) describes research carried out in the US on the problem of controlled thermonuclear fusion over the years 1951-1958. The presentation is largely chronological and is intended for readers with little technical knowledge. It is accompanied by a brief account of the operating principles of various experimental setups. The book gives a clear account of research trends within the "Project Sherwood" program and on the difficulties of realizing certain ideas experimentally.

A wide circle of nonspecialist readers interested in the problem of controlled nuclear reactions will welcome a book entitled Plasma--the Fourth State of Matter by D. A. Frank-Kamenetskiy, 1961, 132 pages. Although this work is intended for engineers and technicians, it is in every way accessible to readers with a secondary education. The basic mathematical apparatus in the book is elementary, with the more difficult passages intended for the qualified reader set off in small print.

THE PHYSICS OF CHARGED PARTICLE ACCELERATION. There are four books on this subject, two of them of a popular scientific nature.

The Betatron, an Inductive Electron Accelerator by L. M. Anan'yev, A. A. Vorob'yev and B. I. Gorbunov, 1961, 351 pages is based on the results of both foreign and Soviet research. The authors have had a great deal of experience in working with betatrons. Their book deals with the following subjects: the theory of electron motion, the electromagnet and its feeder circuit, the vacuum system, injection schemes, beam extraction from the chamber, adjusting elements, protection against radiation. The book is also useful for the case it makes in favor of betatrons of up to 30 mev in energy for various practical purposes (defectoscopy, medicine, chemistry, etc.).

The collection of articles entitled Accelerators, 1960, 124 pages, includes a number of articles on charged particle accelerators. Some of the articles are devoted to a description of a ferrite variator for adapting the cyclotron to the phasotron acceleration range; other papers have to do with a cyclotron with a periodic magnetic field for accelerating multiply-charged ions, and a new scheme of beam extraction from the phasotron, etc. The rest of the articles have to do with problems involved in electron accelerators: a six-mev linear accelerator with a constant phase velocity; the dynamics and grouping of particles in linear accelerators; beam extraction from a betatron; and finally, the problem of electron accumulation in accelerators.

Despite the emergence of new types of accelerators, electrostatic accelerators of charged particles and the cyclotron are the most widely used instruments in nuclear research and various allied practical fields. The scientific popular books by B. M. Gokhberg and G. B. Yan'kov Electrostatic Charged Particle Accelerators, 1961, 51 pages and N. D. Fedorov, The Cyclotron A Cyclical Resonant Ion Accelerator, 1960, 88 pages describe the operating principles, history, and subsequent development of these acceler-

ators which first came into their own several decades ago.

Nuclear Power Production

Books on this subject may be divided into three groups: 1) reference works of a general character, 2) books having to do with the problems of nuclear reactor physics (including reactor theory and design and the physics of radiation protection), and 3) books dealing with the technology and thermotechnology of reactor design and exploitation.

Reference works. These publications are intended for wide circles of specialists interested in the problems of nuclear power production and allied scientific and technical fields; they contain data which can be used directly in their daily work. Among such publications are the following: A Handbook of Nuclear Physics Constants for Reactor Design (by I. V. Gordeyev, R. A. Kardashev, and A. V. Malyshev), 1960, 280 pages; A Brief Handbook for the Engineering Physicist (compiled by N. D. Fedorov), 1961, 507 pages; Dosimetry and Radiation Protection (by R. Eger), from the German, 1961, 210 pages; A Handbook of Water-Cooled Nuclear Reactor Corrosion and Wear, from the English, edited by E. S. Sarkisov, 1960, 404 pages; Power Producing Reactors in the US, from the English, edited by M. I. Minashin, 1960, 85 pages.

The first handbook contains basic experimental data processed and presented in a form convenient for practical use. The first and second chapters include data on neutron cross-sections in the thermal energy range, as well as according to resonance level perameters. The third chapter includes experimental data on inelastic scattering and transport cross-sections. The fourth and fifth chapters contain data on fast and intermediate neutrons, as well as fission product yields and energies. The Appendix describes practical methods for using the above information

The handbook for the engineering physicist is of a more general character and is classified as a work on reactor design by virtue of the fact that most of its material has to do with reactor physics and technology. A specialist in reactor design will find in it that basic information which he most often requires in his daily work. At the same time, the book presents sufficiently details material on accelerator technology, thermonuclear reactions, nuclear physics, the geology of atomic raw materials, isotopes, radiation medicine and biology, and other problems.

The book by R. Eger contains reference material on radiation protection. It contains basic physical constants, concepts, and definitions having to do with the problems of dosimetry and radiation protection. It likewise has tables, formular, and graphs necessary for practical safety calculations.

The handbook on corrosion and wear was written by a group of American specialists. Its value rests in the fact that it contains a large body of factual material relating to the important problem of corrosion and wear of materials employed in the interior portions of water-cooled reactors. The first part of this work contains an examination of the structure of a nuclear power production installation, general data on corrosion and wear, criteria for material selection, as well as a consideration of problems involved in water technology. The second part contains a description of methods for testing materials for resistance to corrosion and wear, along with tabulated experimental data. The third part has to do with special wear and corrosion problems as they relate to material selection and the choice of appropriate nuclear reactor designs.

The handbook on nuclear power production reactors in the US was issued by the US Atomic Energy Commission. It represents a compendium of technical data on 10 major nuclear power producing installations either already operating or being designed and constructed in the US. Each section includes a brief description of the reactor type, its design, special features, auxiliary and control systems, as well as detailed tabulated data on the reactor and its various systems. A considerable number of drawings illustrate the operation of each reactor described.

PUBLICATIONS ON NUCLEAR REACTOR PHYSICS. Five books belong under this heading.

The collection of articles by Soviet authors entitled <u>An Investigation of the Critical Perameters of Reactor Systems</u>, 1960, 118 pages contains original articles having to do mainly with theoretical calculations of neutron streams and critical perameters (masses and volumes) in various reactor systems of the following types: uranium-graphite, uranium-beryllium, and water mixtures of uranium and plutonium. The collection includes graphs and tables which establish the dependence of critical perameters on the relative concentration and character of the fissionable material and retarding agent employed, as well as on fuel enrichment over a wide range of neutron energy spectra.

Intermediate Reactor Physics, edited by J. Sten, from the English, 1961, 626 pages, deals with problems which have not as yet received systematic coverage in Soviet literature. What we refer to is a specific branch of reactor design (reactors with an intermediate neutron spectrum). The book in question goes a long way toward filling the present need for such a work. Although the scope of the book is restricted to an intermediate reactor with a beryllium retarder and sodium heat transfer agent, many of the theoretical and experimental methods described are of a general character and may be useful to specialists working with other types of reactors.

The book by T. Cachan and M. Causy entitled The Physics and Calculation of Nuclear Reactors, from the French, 1961, 392 pages, is the first volume in a three-volume set of texts on nuclear technology. It contains an examination of the foundations of atomic and nuclear physics, a treatment of the phenomenon of radioactivity and the properties of nuclear radiation as well as nuclear fission processes and chain reactions. Some consideration is given to the stationary theory and dynamics of reactors, as well as methods for calculating homogeneous and various types of heterogeneous reactors. The text is illustrated by many numerical examples and characteristics of operating reactors.

Nuclear Reactor Control, by J. Bowen and E. Meisters, from the English, 1961, 96 pages, deals with the probleam of regulating uranium-graphite gas-cooled reactors which have reached their most advanced stage in England. It includes a description of the operation and calculation of reactor control systems and the necessary equipment. There is likewise a treatment of the effects of radiation, reactivity, and velocity of the heat transfer agent on the functioning reactor. Also covered is the problem of reactor stability in intermediate regimes. There is a listing of criteria for apparatus and control systems, with a brief description of instruments for measuring neutron flow.

In his book entitled The Foundations of Reactor Shielding, 1961, 344 pages, G. Goldstein concentrates his attention on a discussion of fundamental research in the field of reactor shielding. In this respect it is unique among books on this subject translated into Russian which as a rule deal mainly with research results and recommendations on the application of these results in engineering calculations.

The book gives a detailed description of equipment especially designed for general experiments on shielding

as well as the results of these experiments, and methods for calculating the passage of gamma rays and neutrons through thick layers of material.

PUBLICATIONS ON THE TECHNOLOGY AND THERMAL TECHNOLOGY OF NUCLEAR REACTORS. This groups includes 8 books - 5 on technology and 3 on thermal technology.

Books on nuclear reactor technology. One of the major problems in power reactor design is the corrosion of materials in reactors with water as the heat transfer agent. The correct solution of water regime problems for nuclear power installations is impossible without a knowledge of corrosive processes taking place at high temperatures and pressures. The collection of articles entitled The Corrosion of Reactor Materials, 1960, 284 pages, edited by V. V. Gerasimov describes methods for corrosion and electrotechnical research, examines the effects of water composition on the corrosion of structural materials, and discusses various forms of corrosion; corrosion under stress, intercrystalline corrosion, and the corrosion of reactor materials. The book contains a large number of experimental data which can be used as a reference source.

D. Hoysington's Foundations of Nuclear Technology, from the English, 1961, 395 pages, deals with basic concepts of material structure and the problems of utilizing atomic energy. Starting out with a very brief exposition of basic physical concepts, the author gradually acquaints the reader with the structure of matter, the properties of atoms and nuclei, natural and artificial nuclear transformations, etc. Much attention is devoted to prospects for the development of nuclear power production, radioactive shielding problems, and apparatus for measuring radiation. From the styllistic standpoint the book should be accessible to a large number of readers without specialized preparation.

The book by H. Crouch, Marine Nuclear Power Installations, from the English, 1961, examines the basic problems encountered in nuclear power system design. The author examines the special characteristics of such installations, their economics, and describes the possible types of nuclear fuel along with methods for the nuclear physical and thermophysical calculations of the active zone. He then proceeds to evaluate the capabilities of the various types of nuclear reactors with reference to marine power production. Much attention is devoted to the problems of safety aboard atomic powered vessels.

Methods for finding optimal values of design variables in nuclear power production systems to assure the lowest

possible costs for electricity produced at atomic installations are described in P. Margen's The Choice of Optimal Variables in Reactor Design, from the English, 1961, 101 pages. The material included applies to uranium-graphite reactors with gas cooling systems. Many of the techniques examined can be applied to other types of reactors, however. It might be said that the book represents a first attempt to present a comprehensive solution to complex optimization problems in nuclear power production.

One of the most important problems in the operation of nuclear reactors is the control of reactor radiation. The book by M. Gausy and T. Cachan entitled Nuclear Reactor Control, from the French, 1961, 174 pages gives a detailed description of apparatus for controlling radiation and reactor regulation. Special attention is devoted to the biological hazards of reactor operation and shielding methods.

Books on the thermal technology of nuclear reactors. Thermoenergetics of Nuclear Installations by B. V. Petunin 1960, 232 pages contains information on nuclear reactors, and the calculation and design of nuclear power installations with steam and gas tubine energy cycles. Also considered are the characteristics of heat transfer agents presently employed, and the technological schemes of the most typical present-day atomic electrical power stations. Also included are data necessary for calculating and designing heat-exchange apparatus and steam generators for atomic electrical power stations.

Basic information on thermodynamics and heat transfer necessary for the design and calculation of heat removal processes from nuclear reactors and the transformation of heat into other forms of energy are described in Applied Thermodynamics and Heat Transfer, by I. I. Novikov and K. D. Doskresenskiy, 1961, 548 pages. Like the other books in this group, this book is useful not only to specialists in the field, but also to undergraduate and graduate students in higher educational institutions.

The problems of heat production in nuclear reactors and methods of removing and usefully utilizing reactor heat are dealt with in Heat Removal and Transformation In Nuclear Reactors, by R. Alamis and P. Ageron, from the French, 1961. One excellent feature of this work is the inclusion of a large number of examples of the calculation of heat removal and utilization, as well as its extremely succinct and systematic style of presentation.

Nuclear Fuels and Materials

NUCLEAR GEOLOGY. This section includes books both on geology and geophysics.

Uranium Provinces, by M. M. Konstantinov and Ye. Ya. Kulikova, 1960, 306 pages, constitutes the most exhaustive compendium to the present time of data on the geology of uranium provinces and deposits in foreign countries. It includes a bibliography covering almost all publications on uranium geology published through 1958, as well as a map of the main ore provinces and uranium deposits in the capitalist countries constructed on the basis of tectonic data.

The first chapter gives a general idea about uranium provinces and their position in the earth's metallogenic scheme, the peculiarities of provinces in various geotectonic structures, as well as the epochs of endogenic and exogenic uranium accumulation in the earth's crust. The authors express a number of new and quite original suppositions of which the most interesting has to do with the predominant location of uranium ores in pre-Cambrian shields at the contact zones between Proterozoic folded belts and more ancient Archean masses. Chapters II-VIII are devoted to a description of uranium provinces and deposits according to separate regions and continents. They include geological and metallogenic characteristics, as well as geotectonic analyses of the territories in question. The inclusion of such general geological and metallogenic information favorably distinguishes this work from earlier publications on the same subject by R. Nayninger, M. Rubo, V. Domarev, V. Kheynrikh, etc. Chapter VIII likewise contains some information on the uranium industrial base of the capitalist countries and the dynamics of its development.

In present day literature, very little attention is devoted to prospecting, surveying, and testing of uranium deposits. This lack is to a considerable extent filled by D. Ya. Shrazhskiy's Methods for Uranium Deposit Prospecting and Surveying, 1960, 240 pages. This book represents a methodological handbook on uranium prospecting and surveying.

Its first section contains a general description of the types of industrial uranium deposits and basic criteria for prospectors. The second part describes prospecting methods according to radiation, gas, and salt aureolae. The "radiation" methods include aerial, ground, and subterranean photography. The only emanation method described is a rapid radon photography technique. The third section covers preliminary and detailed survey methods and calculations of the amount of uranium in the deposit. The

concluding chapter of this section lists basic criteria for the industrial evaluation of uranium deposits as well as certain special techniques for evaluating their richness.

The geological-geophysical servicing of uranium mines is characterized by a number of specific peculiarities. Methods for the Geological-Geophysical Servicing of Uranium Mines, by G. I. Petrov, M. V. Kutenkov, I. M. Tenenbaum, and L. S. Yevseyeva, 1960, 217 pages represents an attempt to cover a complex of geological-geophysical and hydrogeological measures. The book includes a brief morphological and radiological description of uranium deposits. It also covers prospecting and surveying systems employed in uranium mines, methods of geological-geophysical mine documentation, sample taking methods, problems having to do with the sorting, enrichment, and melting of ores, instructions for keeping loss and depletion records, as well as the participation of mine geologists in the planning of mine exploitation work. The last chapter is devoted to the hydrogeological servicing of mines; it describes the various types of mine flooding, methods of combating water, petroleum, and gas in ore-bearing strata, as well as engineering-geological, hydrogeological and radiohydrogeological observations in uranium mines.

The book by Ts. R. Ambartsumyan, G. I. Basalova, S. A. Gorzhevskaya, N. G. Nazarenko, and R. P. Khodzhayeva, Thermal Studies on Uranium and Uranium-Containing Minerals, 1961, 148 pages systematizes and generalizes factual data obtained from thermoanalytic studies of uranium and uranium-containing minerals. The book contains standard heating and dehydration curves, as well as data resulting from studies of changes in the physico-chemical properties of minerals obtained with the aid of crystallo-optical, roentgenometric, microchemical, and luminescent analysis. The minerals are described on the basis of A. G. Betekhtin's classification system.

The book by Yu. M. Dymkov, The Uranium Mineralization of the Rudny Mountains, 1960, 100 pages gives a brief description of the genetic peculiarities of hydrothermal uranium deposits in the oldest mining area of Central Europe. It describes vein formations and parageneses, epochs and stages of mineralization, mineralization phases, mineralization cycles, as well as a number of suppositions regarding interactions between solutions and minerals, the formation of cationic solfatara compositions and hydrotherms, etc. In the author's opinion, the uranium deposits in the Rudny Mountains were formed during the Variscan metallogenic epoch, but that they likewise bear

signs of transformation during the Alpine epoch.

The geochemical interpretation of uranium mineralization processes is based on an analogy with the modern fumarol-solfatara process. It is assumed that as the magma center cooled, it released magmatic gases in a sequence which was to determine the regular alteration of anions in solution. Metals, alkaline earths, and alkalis emerged from the surrounding strata in areas of active interaction with acid solutions.

The book by A. A. Saukov, Radioactive Elements of the Earth, 1961, 161 pages, is one of a series of popular scientific works. It tells of the history of the discovery of radioactive elements and radioactive transformations in uranium, actinouranium, and thorium families; other subjects covered are the structure of the earth's crust, the distribution of various elements and their radioactive isotopes therein, the radium, uranium and thorium content in various rock formations, soils, and natural waters, atmospheric radioactivity and uranium minerals, the earth-energy thermal balance arising as a result of nuclear disintegration of radioactive elements found in the earth's crust, the migration of radioactive elements and geochemical cycles, the genetic types of uranium deposits, and various methods of surveying deposits ofradioactive elements. Written in an interesting and engaging style, this book can be useful to the non specialist interested in radioactive raw materials.

The last several years have seen a considerable expansion of the scope of efforts requiring the determination of the presence of uranium, thorium, and their disintegration products in various substances. Of considerable interest in this connection are radiochemical and radiometric methods which make it possible to determine the presence of uranium and thorium disintegration products by their radioactivity levels alone. The book by V. L. Shashkin entitled Methods for the Analysis of Natural Radioactive Elements, 1961, 152 pages, contains a systematic treatment of the results of 126 research products on methods for determining radioactive elements in the uranium and thorium series published in various foreign and domestic publications through 1960. The seven chapters in this book are concerned with the radioactive properties of natural radioactive elements, radioactivity measurement techniques, physical analysis methods, techniques for determining uranium and thorium isotopes, methods of detecting protactinium, actinium, and radium and polonium isotopes, methods of detecting radium and radon isotopes, and finally, the basic principles of complex

radiochemical analysis.

The brochure by L. N. Posik, I. V. Koshelev, and V. P. Bovin, entitled Radiometric Field Analysis of Ore Samples, 1960, 78 pages is the first generalization of practical experience accumulated by mining enterprises in the field analysis of radioactive ores. It includes a brief examination of the physical principles of the method and the elements of the complex field laboratory. Most of the attention is devoted to the techniques and organization of field analyses with the aid of RKS-1, RKS-2, and RKS-3 installations, methods of determining correction factors, as well as error analysis. The appendix includes technical criteria to be used in the planning of control points with RKS-1 installations.

One of the radiometric techniques used in detecting radioactive ores is the $\beta-\gamma$ analysis technique. This method was developed in 1947 and has since yielded a considerable amount of data. A brochure entitled The Analysis of Radioactive Ores by the $\beta-\gamma$-Method, by Kh. B. Mezhiborskaya, V. L. Shashkin, and I. P. Shumilin, 1961, 64 pages contains a description of modern radioactive ore analysis methods according to β- and γ-radiation measurements. Actually the brochure constitutes as handbook on the analysis of radioactive ores by quantitative radiometric methods.

One of the methods of nuclear physics assuming ever greater importance in the detection of beryllium is the photoneutron technique. The Photoneutron Method of Beryllium Detection, by Kh. B. Mezhiborskaya, 1961, 51 pages deals with the analytic method based on the use of the photoneutron reaction in the beryllium nucleus. It is concerned with the general problems involved in the use of nuclear physics methods in beryllium detection, and likewise includes a description of a laboratory variant of the photoneutron method. Taking into account the special role played by safety techniques in the practical application of nuclear physics methods, the author has included a special set of instructions on safety precautions to be used in working with neutron radiation.

The appended bibliography includes all the latest writings on the above subject published through 1960.

NUCLEAR METALLURGY. Ever greater attention today is being concentrated on the study of uranium and thorium as metals for the purpose of developing new alloys to be used as nuclear fuel. Of definite interest in this connection is the collection of papers by scientists of the Metallurgy Institute imini A. A. Baykov, edited by O. S. Ivanov,

entitled The Structure of Alloys of Certain Systems Containing Uranium and Thorium, 1961, 492 pages. The collection contains the results of extensive studies of the structure, phase transformations, and properties of a number of double, triple, and quadruple alloys based on uranium and thorium, as well as high-melting compounds of these metals, particularly beryllide and carbide oxides. Particularly full treatment is given to the binding of uranium by zirconium, niobium, molybdenum, and chromium, all of which dissolve easily in - uranium and have a relatively small thermal neutron capture cross-section.

Important problems in the metallurgy of uranium and a number of important structural metals are examined in the monograph by G. Ya. Sergeyev, V. V. Titova, and K. A. Borisov, The Metallurgy of Uranium and Certain Reactor Materials, 1960, 224 pages. Along with data on the structure, physical, and mechanical properties of uranium and its alloys, a considerable amount of attention is devoted to the effects of irradiation and thermal cycles on the dimensional and structural stability of fuels and heat-producing element shells, as well as the thermal and thermomechanical treatment of uranium. A separate section deals with the technique of constructiog heat-producing elements with solid metal cores.

A wide range of problems is treated in the second issue of the collected papers from the Metallurgy and Metal Studies Department of the Moscow Engineering Physics Institute, entitled The Metallurgy and Metallic Properties of Pure Metals, edited by V. S. Yemel'yanov and A. I. Yevstyukhin, 1960, 336 pages. The collection includes 27 papers which are concerned with such subjects as the refinement of chromium, niobium, and thorium, as well as the physical and corrosive properties and diffusion characteristics of zirconium and its alloys. Desriptions are given of apparatus and methods for measuring internal friction in zirconium, niobium, uranium and their alloys. Also included are the results of studies on the diffusion of sulphur, phospherous, carbon, and binder components in stainless steels.

Beryllium, Its Chemical Technology and Metallurgy by G. F. Silina, Yu. I. Zarembo, and L. E. Bertina, 1960, 120 pages, constitutes a critical generalization of published materials and contains a description of nuclear, mechanical, corrosive, and chemical properties of beryllium. Also described are industrial methods of obtaining pure beryllium and its compounds.

It would likewise be apropos at this point to mention the book by M. Sittig, Sodium, Its Production, Properties,

and Uses, from the English, 1961, which deals with one of the more promising heat transfer agents used in nuclear reactors.

A special place among publications in this catagory belongs to the book by G. N. Balasanov, The Foundations of the Automation of Technological Processes in the Hydrometallurgy of Rare and Radioactive Metals, 1960, 296 pages. In relatively compact form the author discusses basic information on presently available automatic equipment, characteristics of regulated objects, and methods of calculating and designing automatic control and regulation systems.

From among the foreign publications, we should give special mention to The Technology of Uranium Production by C. Harrington and A. Ruhele [see also the section on the chemistry of nuclear materials below], from the English, 1961, 586 pages. This monograph covers a wide range of problems in the study of uranium metallurgy, properties, and processing technology. Separate chapters deal with the production of metallic uranium both by reduction with subsequent remelting and by the direct reduction of tetrafluoride. Detailed consideration is given to forging processes in the alpha phase by means of primary presses and rolling and mechanical treatment mills. Recommendations for safety measures are also included.

Certain to be of interest to scientific workers and engineers employed by scientific research institutes and industrial enterprises is the first collection of surveys issued by the Battle Institute entitled Nuclear Fuel Materials, from the English, 1961, 273 pages. Also in this category is the collection entitled The Extraction and Purification of Rare Metals, from the English, 1960, 512 pages. The 22 papers in this collection, first presented at a symposium at the London Mining and Metallurgy Institute, contain the results of laboratory and semi-industrial studies on the technology of uranium, thorium, beryllium, titanium, zirconium, hafnium, niobium, vanadium, selenium, and other rare metals. The collection contains a wide range of experimental data as well as a number of theoretical generalizations and critical remarks made in the course of discussions.

THE CHEMISTRY OF NUCLEAR MATERIALS. Books in this category are conveniently grouped according to the following subheadings: "General Chemistry", "Analytical Chemistry", "Chemical Technology".

One of the interesting publications in the first subcategory, is The Chemistry of the Actinide Elements, by

G. Seaborg and D. Katz, 1960, 542 pages, supplemented by materials published in mid-1959. This monograph contains sufficiently complete data on actinide chemistry and can serve both as a text and a reference.

The Chemistry of Extraction Processes, by V. V. Fomin, 1960, 166 pages contains a generalization and analysis of modern theoretical concepts on the extraction mechanism, one of the most important processes in modern chemical technology. Along with other problems, the author examines the dependence of distribution coefficients on the concentration of the extragenic composition of the water phase and the electrolytic dissociation in the organic phase.

Two books deal with problems in analytical chemistry. These are Uranium and the Methods its Determination, by S. V. Yelinson, V. K. Markov, A. V. Vinogradov, A. Ye. Klygin, and I. V. Moiseyev, 1960, 264 pages, and Zirconium: Chemical and Physical Methods for its Analysis, by S. V. Yelinson and K. I. Petrov, 1960, 212 pages.

The first of these contains a systematic treatment of information accumulated over the last few years in the field of the analytic chemistry of uranium. After describing the physical and chemical properties of uranium and several of its compounds, the authors give detailed consideration to methods for the qualitative detection and isolation of uranium, as well as weight, volume, photometric, electrometric, luminescent, and radiometric methods of uranium detection.

The book by S. V. Yelinson and K. I. Petrov is concerned with the chemical and physico-chemical properties of zirconium and its compounds; it includes the basic analytic reactions and describes the more reliable photometric, radiometric, spectral, roentgenospectral, chemical, and physical methods of detecting zirconium and various admixtures.

A somewhat greater number of publications falls into the category of "Chemical Technology". In it, the reader will find books dealing both with the general technology of nuclear materials and the technology of individual elements and compounds.

The book by Ya. I. Zil'berman, The Foundations of the Chemical Technology of Artificial Radioactive Elements, 1961, 332 pages, contains a systematic survey of information on the chemical technology of radioactive elements, mainly on the reprocessing of irradiated nuclear fuel. The book likewise touches on problems involved in the chemical and biochemical effects of ionizing radiation. The simplicity and compactness of this work make it an ideal

text for undergraduate and graduate students in the appropriate fields.

Also of the textbook variety is the work by M. Benedict and T. Pitford entitled The Chemical Technology of Nuclear Materials, 1960, 528 pages, from the English. It includes a comprehensive treatment of methods for obtaining materials used in nuclear technology as well as methods for reprocessing irradiated materials. Certain problems in nuclear physics and apparatus employed are discussed as supplementary material. Considerable attention is devoted to the processes of isotope extraction and separation which are assuming industrial importance along with the development of nuclear power production.

Among the publications deveoted to the problems of chemical technology, we should note Uranium Technology by V. B. Shevchenko and B. N. Sudarikov, 1960, 330 pages, based on a series of lectures presented by the authors at the Moscow Chemical Technology Institute of the Order of Lenin imini D. I. Mendeleyev. After a brief introduction and description of the chemical and physico-chemical properties of uranium and its compounds, the authors proceed to consider uranium ores and minerals, their mechanical and high-temperature processing and leaching. They then examine sedimentation, sorption, and extraction methods of treating uranium ore suspensions, as well as problems having to do with uranium refining, oxide production, uranium tetra- and hexafluoride, and finally the preparation of metallic uranium.

The book by N. P. Galkin and B. V. Tikhomirov entitled The Basic Processes and Apparatus of Uranium Technology, 1961, 220 pages, generalizes materials in this field published in recent years. The survey includes papers on the mechanical processes involved in the treatment of solid materials and mixing in liquid media, as well as classification and dehydration processes. Also presented are the general mass-transfer laws which simplify the study of diffusion processes, including solution, ion exchange, extraction, crystallization and drying.

Problems in chemical technology are likewise considered in the first part of the book by C. Harrington and R. Ruhele, The Technology of Uranium Production, 1961, 586 pages. The range of problems considered is limited to the chemistry of the process involved in ore concentrate exposure, extraction processes, uranyl nitrate decomposition, and tetrafluoride production. Also included are purification processes based on ether and tributylphosphate extraction. The second part of the book is concerned with technological schemes for uranium compound production.

The Chemistry and Technology of Uranium-Fluorine Compounds, by N. P. Galkin, A. A. Mayorov, U. D. Veryatin, B. N. Sudarikov, N. S. Nikolayev, Yu. D. Shishkov, and A. B. Krutikov, 1961, 349 pages constitutes a detailed survey of research papers published prior to June 1960 on the physico-chemical properties and methods of producing the main fluorine compounds of uranium. Consideration is given to the fluoride-distillation reprocessing of irradiated nuclear fuel, as well as the chemistry and technology of fluorine, hydrogen fluoride, and halogenfluorides.

A brief description of the properties of uranium and its ions, information about uranium ores, safety techniques in the purification of uranium concentrates and, what is more important, a description of the theoretical and technological processes of uranium concentrate reprocessing up to the level of pure salts and metallic uranium, compiled on the basis of published data, will be found by the reader in The Technology of Uranium Concentrate Reprocessing, by N. P. Galkin, A. A. Mayorov, and U. D. Veryatin, 1960, 162 pages.

Of the books dealing with the chemical technology of individual elements, we should mention the survey work by G. Ye. Kaplan, G. A. Uspenskaya, Yu. M. Zarembo, and I. V. Chirkov, entitled Thorium, its Raw Material Resources, Chemistry and Technology, 1960, 224 pages, which contains a description of the physico-chemical, corrosive, and radioactive properties of thorium; consideration is also given to the analytical chemistry and technology in the production of thorium compounds. The survey likewise covers a number of problems involved in the metallurgy and processing of compact and powdered metallic thorium.

Lithium, its Chemistry and Technology, by Yu. I. Ostroushko, P. I. Buchikhin, V. V. Aleksayev, and a large group of co-authors, 1960, 200 pages also belongs in this category. Together with an examination of the most important minerals, geochemical and physico-chemical properties of lithium and its compounds, the technology of lithium ore reprocessing and the analytical chemistry of lithium, a considerable portion of the book is devoted to the problems of lithium ore enrichment and metallurgy, interest in which has grown inconnection with the possibility of using this element in reactors as a heat transfer agent. The survey is compiled on the basis of data published in domestic and foreign sources over the period 1818-1958.

At this point, we might also mention Ion-Exchange Membranes and Their Applications, by B. I. Laskorin, and B. M. Smirnova, 1961, 163 pages, devoted to one of the more important modern areas of chemical technology--the

use of electrodilysis with ionite membranes in radiochemical production, uranium metallurgy, and water desalination.

A special place among books in this category belongs to The Theory of Isotope Separation in Columns by A. M. Rozen, 1961, 284 pages, a generalization of the author's papers published since 1945. In the first part of the book, the author examines allof the most important countercurrent separation processes from the standpoint of basic mass-transfer laws, and establishes a connection between engineering and physical concepts as to the motive force behind the process. The second part of the book deals with general methods for calculating columns and cascades. This is followed by a derivation of the general theory of separation; optimal peramaters are chosen on the basis of the theory of similiarity of non-stationary processes. This book bears a close relationship to a monograph by M. P. Malkov, A. G. Zel'dovich, A. B. Fradkov, and I. V. Danilov entitled The Production of Deuterium from Hydrogen by the Deep Cooling Method, 1961, 151 pages. This book contains the physico-technical foundations of the method, the results of studies on diluted mixture rectification, and schemes for industrial installations. Also considered are methods for hydrogen purification and gas mixture analysis.

(To be continued in the next issue).

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